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FLIGHT TEST RESULTS OF THE USE OF ETHYLENE GLYCOL MONOMETHYL ETHER (EGME) AS AN ANTI-CARBURETOR ICING FUEL ADDITIVE

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16. Abstract

This report documents the results of a Flight Test Program to evaluate the effectiveness of Ethylene Glycol Monomethyl Ether (EGME) as an anti-carburetor icing fuel additive. The Flight Test results show that EGME reduces the formation of carburetor ice during cruise power, and that the effectiveness of EGME reduces as the throttle is closed. Based on these results, EGME should not be considered as an anti-carburetor icing fuel additive in lieu of carburetor heat.

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FLIGHT TEST RESULTS

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ETHYLENE GLYCOL MONOMETHYL ETHER (EGME)

AS AN ANTI-CARBURETOR-ICING FUEL ADDITIVE

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July 1979

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ABSTRACT

The effectiveness of 0.15 percent by volume of ethylene glycol monomethyl ether (EGME) as an anti-carburetor-icing fuel additive was investigated inflight using a PA-23 airplane equipped with O-320-A engines. The test fuel was fed to one engine, and the other used stock aviation gasoline as a control. The results of this testing show that EGME is quite effective in preventing carburetor ice in cruise. Both the maximum severity of icing and the range of environmental conditions conducive to its formation were reduced.

During descents, the results were not so clear-cut. While the average rate of carburetor ice formation was reduced, there are certain conditions of temperature and dew point which appear to enhance the formation of carburetor ice during landing approaches.

Based on these results, it appears that EGME can be quite useful in preventing carburetor ice accidents during cruise and higher power setting flight phases. If questions concerning the long term use of the additive in aero engines and the apparent increased icing rate in descents can be satisfactorilly resolved, then EGME should be added to aviation gasoline on a routine basis.

Because of mixing problems, the use of aerosol spray cans is not recommended as a means of adding EGME to fuel.

PREFACE

This report documents the results of a flight test program to evaluate the effectiveness of ethylene glycol monomethyl ether (EGME) as an anti-carburetor-icing fuel additive. The support for the testing was provided by the Federal Aviation Administration under contract number DOT-FA78WA-4165. Mr. J. E. Davis was the Contracting Officer. Mr. C. R. Ritter acted as Technical Officer, succeeding Mr. W. T. Westfield.

The Principal Investigator for the program was Mr. Richard L. Newman, who also acted as Project Pilot. Copilots for the testing were Mr. Jack Crouch, Ms. Caroline Snell, and Mr. Terry Lutz.

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INTRODUCTION

Background

For the past several years, carburetor ice formation has been one of the primary causes of engine failure in general aviation airplanes. Carburetor ice is caused by the cooling of moist air within the carburetor and disrupts the flow of fuel and air to the engine. A 1977 report to the FAA(1)* examined the accident records of the NTSB and concluded that carburetor ice causes approximately 140 accidents per year within the US. Of these accidents, only half are identified as having been so caused.

This same report reviewed the state-of-the-art in carburetor ice prevention/elimination and recommended a flight test program as part of an overall effort to reduce the impact of carburetor ice on the general aviation fleet. The present paper is a summary of the results of such a flight test.

Before describing the results, some introductory paragraphs are necessary to acquaint the reader with the state-of-the-art. For a complete summary, the report previously cited is recommended and has an extensive bibliography.

Accident Statistics. During the period 1969 to 1975, the NTSB files produced a list of 468 accidents where the probable cause was officially listed as "engine failure -- carburetor/induction system icing." This includes 421 accidents to single-engine airplanes, 31 to multi-engine airplanes, and 16 to helicopters and autogyros. These accidents produced 44 fatalities, 202 serious injuries, and destroyed 75 aircraft. In addition to these accidents, where carburetor ice has been reported,

* Underlined numbers in parentheses denote references at the end of the report.

there are approximately 180 accidents per year caused by engine failure where the specific cause of the engine failure could not be determined. It has been suggested elsewhere (2) that a large proportion of these accidents might be caused by carburetor ice. A review of a sample of such reports has confirmed this supposition. Reference (1) estimates that the official number of carburetor ice accidents is low by a factor of about 100 percent. An annual cost of two million dollars per year was assigned to the carburetor ice accidents. This figure is equivalent to 7.2¢ per flight hour.

Previous Carburetor Ice Studies. For the most part, today's state-of-the-art in carburetor ice design and prevention stems from the NACA work of the 1940s. A 1949 NACA report (3) serves as the design guide for light airplane ice protection today. However, two major developments since that time have potential bearing on the carburetor ice problem. These are the application of anti-icing fuel additives or carburetor coatings and the development of carburetor ice detection equipment.

In the late 1960s, Gardner and Moon (4) reported on dynamometer tests with a variety of fuel additives in an attempt to find a solution for carburetor ice. These tests were all performed using an automotive engine equipped with a typical updraft aviation carburetor. The environmental conditions were those equivalent to 40 degree air and nearly 100% saturation. The two most effective fuel additives were hexylene glycol and ethylene glycol monomethyl ether (EGME). While hexylene glycol reduced the formation of carburetor ice more at the optimum concentration, EGME was much less sensitive to concentration variations. Accordingly, Gardner and Moon recommended that EGME be added to aviation fuel in the proportion of 0.15%(by volume).

Gardner and Moon also investigated the effect of applying slippery coatings to the carburetor surfaces. They used several proprietary carburetor detergents and a Teflon(R) spray. These produced a slippery coating to which the ice would not adhere. They concluded that the combination of slippery coatings and EGME would eliminate carburetor ice as a problem. As a result of their recommendation, EGME may be added to aviation gasoline in Canada on an optional basis. However, there have been no reports of its use in flight since the dynamometer tests were run in the 1960s.

EGME has been approved for addition to the fuel by the engine manufacturers and by two airframe companies (Piper and Aero Commander).

It must be pointed out that EGME is quite soluble in water. This property ensures that the EGME will be absorbed into the condensing moisture within the carburetor. However, this tendency may influence the long term storage problems which should be investigated before routine addition to aviation gasoline becomes common.*

Also marketed within the past few years have been a variety of carburetor ice detectors. While no independent assessment of these detectors for reliability and effectiveness has been made, they do hold the promise of enhancing the pilot's ability to detect the onset of carburetor ice.

Description of Carburetor Icing. There are three types of carburetor or induction system icing: impact icing, throttle icing, and fuel vaporization icing. Impact icing is formed by moisture laden air striking elements of the intake system at temperatures slightly below freezing. It is very similar to airframe icing and forms in much the same conditions. Prevention of impact icing is beyond the scope of this report.

The second type of induction system icing, throttle icing, occurs when moisture in the air condenses and freezes because of cooling as the air passes through restrictions, such as throttle butterflies,

* EGME is added to all military turbine fuels with no reported storage problems, so this concern may be overplayed.

inlet guide vanes, or venturis. The acceleration of the air produces a pressure drop which in turn results in a temperature drop. The temperature drop can approach thirty degrees F in a carburetor venturi.

Fuel vaporization icing is caused by the cooling resulting from evaporation of the fuel within the carburetor. As any liquid evaporates, a certain amount of heat must be extracted from the surroundings. In a gasoline engine carburetor, the average cooling (based on a stoichiometric mixture) will be approximately 37 F. The total cooling in a venturi carburetor, vaporization plus throttling, can be as much as 70 F, according to Coles <u>et al.</u>(3). Because of the additive effect of vaporization and throttling cooling, vaporization icing is especially serious in venturi carburetors.

According to Coles (5), the critical factors for ice formation are carburetor inlet temperature, humidity, and throttle angle. He did not find that fuel temperature or the amount of excess free water was significant. Figure 1, adapted from Coles' report, shows the regions of serious ice formation (in terms of temperature and dew point) for a venturi carburetor at several power settings.

Operating variables which affect the formation of carburetor ice include throttle settings, mixture settings, and the use or non-use of carburetor heat. As we have discussed, power settings requiring small throttle openings tend to be more susceptible to ice formation. It would seem that flight at high altitudes would have a reduced tendency to icing because of the large throttle openings required.

Coles and his co-workers (3) state that the mixture has a negligible effect on the formation of ice because not all of the fuel is evaporated within the carburetor at the leanest possible settings. They noticed no temperature change within the carburetor as the mixture was enriched from these leanest settings. This is in conflict with

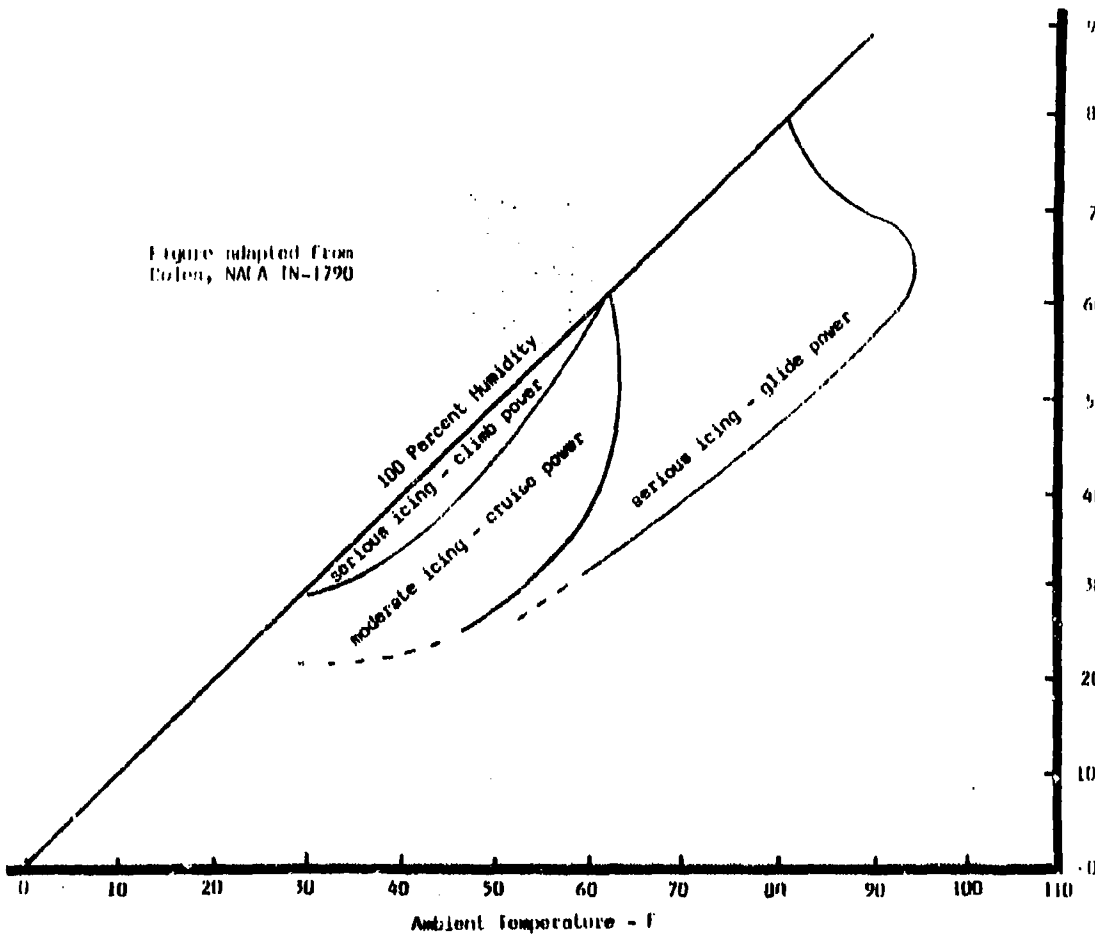

FIGURE 1

CONDITIONS FAVORABLE FOR CARBURETOR ICE

Diblin (6), who says that the mixture ratio can have a very significant effect on the rate of carburetor ice formation.

Conclusions Reached in Earlier Report

In the earlier report on carburetor ice (1), several conclusions were reached concerning steps that should be taken to reduce the number of carburetor ice accidents. A three-fold program was recommended.

Fuel Additive Study. The most promising single solution cited was the fuel additive work begun by the Canadians Gardner and Moon (4). Their primary recommendation was to add 0.15% (by volume) of EGME to aviation gasoline. Secondary recommendations included the further addition of carburetor detergents or the use of a Teflon(R) coating on carburetor parts to minimize adhesion of the ice. Several developmental tests were recommended to validate Gardner and Moon's conclusions:

1. Conduct further testing to ensure that EGME will be effective at temperature and humidity conditions beyond those already tested (40 F and nearly saturated air);
2. Extend the tests of EGME to determine if the additive will remain effective at reduced concentrations;
3. Perform an in-flight validation of EGME in a typical general aviation airplane;
4. Conduct a long term study to ensure that EGME will not prove harmful to the engine over a long period of use; and
5. Determine the extent of the storage problem, if any, if EGME is added to aviation gasoline at the refinery or distribution center.

Additional tests were recommended to validate the conclusions of

Gardner and Moon regarding the carburetor detergents.

Education Program. The carburetor ice report also suggested a program to fill several serious holes in carburetor ice awareness among pilots, aircraft manufacturers, and aircraft accident investigators. It recommended preparing a pilot-oriented paper for wide distribution, discussing carburetor ice, its effect, and the pilot techniques available to cope with it. A second recommendation was to develop, in concert with the manufacturers, a set of consistent operating procedures which would be both effective and appropriate for the various aircraft/engine combinations. A final recommendation proposed a training syllabus to ensure that FAA and NTSB accident investigators are fully aware of carburetor ice and the techniques for detecting it after an accident. This would, it was hoped, reduce the number of accidents that are mis-classified as "engine failure -- undetermined cause."

Additional Research. The report also recommended that carburetor ice research not be limited to the fuel additives, but be expanded to include such ideas as anti-adherent coatings and ice detectors.

Objectives of This Study

The overall objective of the carburetor ice flight test was to validate the effectiveness of EGME as an anti-carburetor-icing fuel additive. The primary emphasis was to be on its effectiveness at the normal concentration of 0.15%.

Secondary objectives included establishing the environmental conditions over which the carburetor is likely to form ice and to measure the rate of ice formation.

Additional objectives were to include determining the effectiveness of various procedures for de-icing a carburetor and to estimate the maximum amount of icing that could be safely tolerated.

TEST EQUIPMENT

Aircraft Description

The airplane used for this test program was a Piper PA-23-150, Apache (serial no. 23-130). The PA-23 is a twin-engine, low-wing airplane equipped with two AVCO-Lycoming O-320-A air-cooled engines. The test airplane was equipped for instrument flight and included an altitude reporting transponder, two VOR/ILS receivers, and an ADF receiver in the radio/navigation package. Aircraft specifications from the airplane manual (7) are shown in Table I.

The test airplane was equipped with two newly remanufactured O-320-A3B engines. These engines were remanufactured to zero-time tolerances by AVCO-Lycoming and had serial numbers RL-748-27B (left) and RL-3107-27B (right). Overhauled hydraulic pumps, propeller governors, and propellers were also installed prior to the start of testing.

Engine instruments included tachometers, manifold pressure gauges, inlet temperature gauges, and the normal oil pressure, temperature, etc. instruments. The tachometers were calibrated by AVCO-Lycoming at the time of engine installation, using a reed-type vibration indicator. The manifold pressure gauges were calibrated by checking the indicated pressures against an FAA-certified altimeter and converting the indicated altitudes to pressures using a standard atmosphere table. All temperature probes, except the EGT, were checked against an ASTM certified thermometer.

Prior to beginning the flying, ALCOR exhaust gas temperature (EGT) analyzers were installed in each engine's exhaust system to read the EGT for each cylinder. At the same time, Richter carburetor air temper-

Description	Value
Engines	2 Lycoming O-320-A
Horsepower	150 hp at 2700 RPM
Maximum Takeoff Weight	3500 lbs
Empty Weight	2261 lbs (Note a)
Useful Load	1239 lbs (Note a)
Wingspan	37 ft
Wing Area	204 ft^2
Length	27 ft 1 in
Height	9 ft 6 in
Propeller Diameter	76 in (nominal)
Power Loading	11.7 lbs/hp
Wing Loading	17.2 lbs/ft^2
Fuel Capacity	72 gal (432 lbs)
Wheel Base	7 ft 3 in
Wheel Tread	11 ft 3 in
Maximum Level Flight Speed	157 knots
Normal Cruise Speed	141 knots
Stall Speed, Flaps Down	51 knots
Sea Level Rate of Climb(both eng)	1350 ft/min
Sea Level Rate of Climb(single eng)	240 ft/min
Service Ceiling	18000 ft
Single Engine Absolute Ceiling	6750 ft
Fuel Consumption, 75% Power	18.8 gal/hr
Fuel Consumption, 65% Power	16.3 gal/hr
Note a: Specific value for Airplane S/N 23-130	

TABLE I

SPECIFICATIONS FOR PA-23 AIRPLANE

ature probes were installed in the carburetor venturis.

The fuel system of the PA-23 consists of two 36 gallon nylon and neoprene fuel cells located outboard of the engine necelles. Normally each tank delivers fuel to the engine on the same side of the airplane. With the exception of specific tests (described later), the normal arrangement of right-tank-to-right-engine and left-tank-to-left-engine was followed throughout the program. Normal 80 octane aviation gasoline was used where available. 100 LL aviation gasoline was substituted when 80 octane was not available.

The same fuel was used in both tanks, except that after the initial testing, 0.15 percent by volume ethylene glycol monomethyl ether was added to the left tank using aerosol spray cans. The EGME used was Prist(R) manufactured by Houston Chemical Company. Periodically during the testing, fuel from the right tank was used in the left engine to confirm that it was still susceptible to carburetor icing. On several occasions, fuel from the left tank was fed to the right engine to determine the de-icing capability of EGME.

Instrumentation

All data was hand-recorded. The flight parameters of interest are listed in Table II. Aside from the free air temperature and the wet bulb thermometer readings, all test data were obtained from the aircraft instruments. The temperature/dew point data was obtained from a Fisher Scientific psychrometer which was extended through the pilot's clear view window. All data listed in this report will be expressed in terms of calibrated data.

Test data was recorded at fifteen minute intervals except where the icing rates were occuring rapidly. In these cases, the data was recorded at shorter intervals as necessary. On occasion, one minute intervals were required.

DATA DESCRIPTION	INSTRUMENT	UNITS	CALIBRATION
Pressure Altitude	Aircraft Altimeter	feet	FAA Certified Repair Station Calibration
Ambient Temperature Wet Bulb Temperature	Fisher Psychrometer	deg F	ASTM Certified Thermometers
Manifold Pressure (each engine)	Engine Gauges	inches Hg	Calibrated using FAA calibrated altimeter and standard atmosphere table
Engine Speed (each engine)	Engine Gauges	RPM	Calibrated using reed-type vibration indicator
Throttle Position (each engine)	Scale on Throttle	arbitrary	None
Carburetor Temperature (each engine)	Richter Indicator	deg C	Checked at room temperature with ATSM thermometer
Inlet Temperature	Aircraft Gauges	deg F	not calibrated
Exhaust Gas Temperature (each cylinder)	ALCOR Analyzer	deg F (change)	Calibrated using ALCOR procedures. Reference at sixty-five percent power/full throttle.

TABLE II

INSTRUMENTATION SUMMARY

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Additional Equipment

Periodically throughout the tests, fuel from the left tank (with EGME added) was withdrawn and analyzed for EGME concentration using a freeze point determination. The test consists of adding 10 ml of distilled water to 500 ml of fuel in a separatory funnel, mixing well, and withdrawing the water. The EGME in the fuel will migrate to the water and lower its freezing point by an amount proportional to the concentration. The reduction of the freezing point is measured with an ASTM certified thermometer. A calibration chart (8) provided the conversion to yield EGME concentration in the fuel sample.

METHOD

Flight Profiles

Two flight profiles were used to obtain carburetor ice. A normal profile was used for steady state icing at cruise and higher power settings. A descent profile was used to obtain carburetor ice during descents at reduced power. Early in the program, descent power icing was attempted using one engine at normal power and one at reduced power. However, the differences between the icing rates as a function of the power made interpretation difficult. As a result, the descent profile was adopted. Although less precise, it does show differences between the two engines.

Normal Profile. Once the altitude and geographical location had been decided upon, the airplane was flown to the particular area (usually this was a holding pattern near the Springfield, Ohio airport), and the desired flight conditions (throttle, propeller, and mixture settings) established. The airplane was flown in these conditions until a power loss rate could be measured or the absence of ice confirmed before changing either the test conditions or the geographical location.

Descent Profile. In order to obtain data with near idle power, a descent to a normal landing was made from approximately three to four thousand feet. Carburetor heat was not used during this descent. Following a normal landing, the aircraft was taxied to the parking area and a carburetor ice check made to see how much ice had accumulated.

Test Procedures

The typical test flight was conducted with a crew of two pilots under instrument flight rules. The only exceptions to this were those flights made at altitudes below the minimum IFR altitude, which were made under visual flight rules. These typically included a few low altitude (2000 or 2500 feet) steady state flights and several flights where a series of VFR landings were made during the day as the temperatures warmed up. Additionally, some data was obtained on cross-country flights with one pilot aboard the airplane. ATC radar coverage was used on all flights except those in the immediate traffic area of an airport.

All flight procedures used were "normal" PA-23 operating procedures (7), except as noted.

The carburetor heat function was tested during the engine run-up to ensure that heat was available. Following this check, carburetor heat was only used in-flight or after landing to test for ice formation (or as a last resort for safety of flight).

Tests for Carburetor Ice Formation. The accumulation of carburetor ice formation was monitored by recording the manifold pressure drop and the variations in the mixture (from the EGT distribution) as functions of time. Once a power loss had developed to a significant degree, carburetor ice was verified by applying full heat for a sufficient time to remove the ice and noting the increase in manifold pressure following its removal. The amount of ice was measured by the change in manifold pressure from before the application of heat to the manifold pressure following the removal of heat.

On occasion, the engines did not show any measurable loss in power, but did exhibit roughness or variations in the mixture distribution on the engine analyzers. If addition of heat corrected this problem, then carburetor ice was reported as "trace." In addition, if the rate of carburetor ice accumulation was less than 0.5 inches per hour or if the manifold pressure drop was 0.1 inch or less, then "trace" was reported. In the particular case of descent profiles, the throttles were opened to fifteen inches of manifold pressure before conducting this check for ice formation.

Operation of Engine Controls. In the normal profiles, following arrival at the holding fix, the power was set to the manifold pressure or throttle position desired. The engine speed was set to the minimum value giving smooth operation without the sound of laboring, subject to the limitations in the AVCO-Lycoming manual (9).

Except for those tests where the mixture was to be operated at full rich, the mixtures were leaned to the degree recommended by the manufacturer. The mixture was leaned until the hottest cylinder reached a peak or the reference temperature used in the ALCOR calibration (equivalent to 65% power). The hottest cylinder was usually number 3 for the left engine and either number 3 or 4 for the right engine. At some low power settings, the engines ran rough before reaching peak EGT. In these cases, the leanest mixture giving smooth operation was used.

During descents, the engines were operated full rich.

Throttle motion was restricted during normal profiles by tightening the throttle quadrant friction to the maximum value.

Environmental Data. The environmental conditions were measured at the beginning of the test immediately after the engines were set to the desired power. Temperature and wet-bulb temperatures were monitored throughout the flight and changes noted. A note was made if the flight was made in clouds or in rain. In the case of descent profiles, the reported temperatures and dew points were based on ground data. If official weather data was available at the airport of landing, then these values were used. If not, then a wet and dry bulb temperature reading was made following engine shut down.

The dew point was calculated using the tables and equations of Reference (10).

Fuel Additive

The initial tests were made with no EGME added to either fuel system. This was done to verify that both engines were equally susceptible to carburetor ice formation. After approximately thirty hours of testing, predominantly at 75% percent power*, no difference in engines could be detected. At this point, EGME was added to the fuel in the left fuel tank.

At intervals, the left engine was operated from the right fuel tank using the cross-feed. This was done to ensure that it (the left engine) would still ice up when operated on normal aviation gasoline.

Also at intervals, the treated fuel was fed to the right engine after carburetor ice had formed in an attempt to determine the de-icing capability of EGME treated fuel.

Fuel Additive Addition. The ethylene glycol monomethyl ether was supplied in aerosol spray cans with an adapter to fit over the end of the refueling nozzle. The EGME was Prist(R) brand, manufactured by Houston Chemical Company. Because the spray cans were designed for the higher flow rates of turbine refueling trucks, the Prist(R) flow rate was in excess of that needed for aviation gasoline. The cans were set to deliver 0.15% of EGME at a fuel flow rate of 30 gpm. During the addition of EGME to aviation gasoline, a calculated spray rate of 2 seconds of spray per gallon of gasoline was used to deliver the optimum concentration. This flow rate was begun five to ten seconds after fueling was started and continued until the desired amount of EGME had been delivered.

Fuel Additive Analysis. At intervals throughout the testing, samples of fuel were withdrawn from the left fuel tank, using the tank drains. The EGME concentration was analyzed using the freeze

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* The high power settings were required to break in the newly remanufactured engines according to AVCO-Lycoming recommendations.

point method (8). This involved draining a 500 ml sample of fuel from the tank. Except for one analysis, the concentration agreed with the predicted value within the experimental error of the analysis.

On one occasion, the concentration was much higher than expected. One gallon of fuel was drained, then a second 500 ml sample was obtained. This second sample analyzed as expected.

Based on a repeatability of the freeze points, the results of the analysis are considered valid to plus or minus 25%. Aside from the one test described above, all analyses agreed with the concentration calculated from the Prist(R) flow rates and the amount of fuel delivered within this error.

RESULTS

Presentation of Data

The power loss rate was found by dividing the amount of power regained (following the application of heat) by the exposure time. This results in a rate of ice formation in terms of inches of manifold pressure lost per hour. These rates are grouped into several classes of icing severity. While these classes are arbitrary, they do serve to indicate the rate of ice formation.

To aid in interpreting these classifications, the expected time to engine failure can be estimated from the rate of manifold pressure loss. Approximately ten inches of manifold pressure loss can be expected to cause engine failure. This figure was found from the minimum tolerable manifold pressure (fifteen inches) found in the early testing and from the maximum available manifold pressure of twenty-five inches at low cruise altitudes. Table III lists the severity classifications in terms of manifold pressure rates and times to engine failure.

During descents, it was not possible to obtain rates, only the total manifold pressure lost during the descent. This is caused by variations in the amount of power used during the approach and the times of the approaches. These varied considerably, usually because of ATC constraints. As a result, the very rough classifications of light, moderate, and heavy will be used, based simply on the amount of manifold pressure drop noted. Direct comparisons between steady state and descent classifications should be avoided.

The effect of altitude, throttle position, and power developed are

CARBURETOR ICING SEVERITY	NORMAL (CRUISE) PROFILE		DESCENT PROFILE
	Rate of Power Loss	Estimated Time To Engine Failure	Amount of Power Loss
None	none detected	--	none detected
Trace	less than 0.5 in/hr	more than 20 hrs	--
Light	0.5 to 5 in/hr	2 to 20 hrs	0.1 to 0.5 in
Moderate	5 to 10 in/hr	1 to 2 hrs	0.5 to 1.0 in
Heavy	10 to 20 in/hr	½ to 1 hr	more than 1.0 in
Severe	more than 20 in/hr	less than ½ hr	--

TABLE III

CARBURETOR ICING CLASSIFICATIONS

all interrelated in a normally aspirated engine such as the O-320. For this reason, it is difficult to separate the effects of variations in all of these parameters. The variable that appears to be the most significant is the throttle butterfly angle or throttle position. Therefore our data are grouped by throttle position rather than altitude or power developed. The data are grouped by "High," "Medium," "Low," and "Descent" power. The throttle positions corresponding to these groups are:

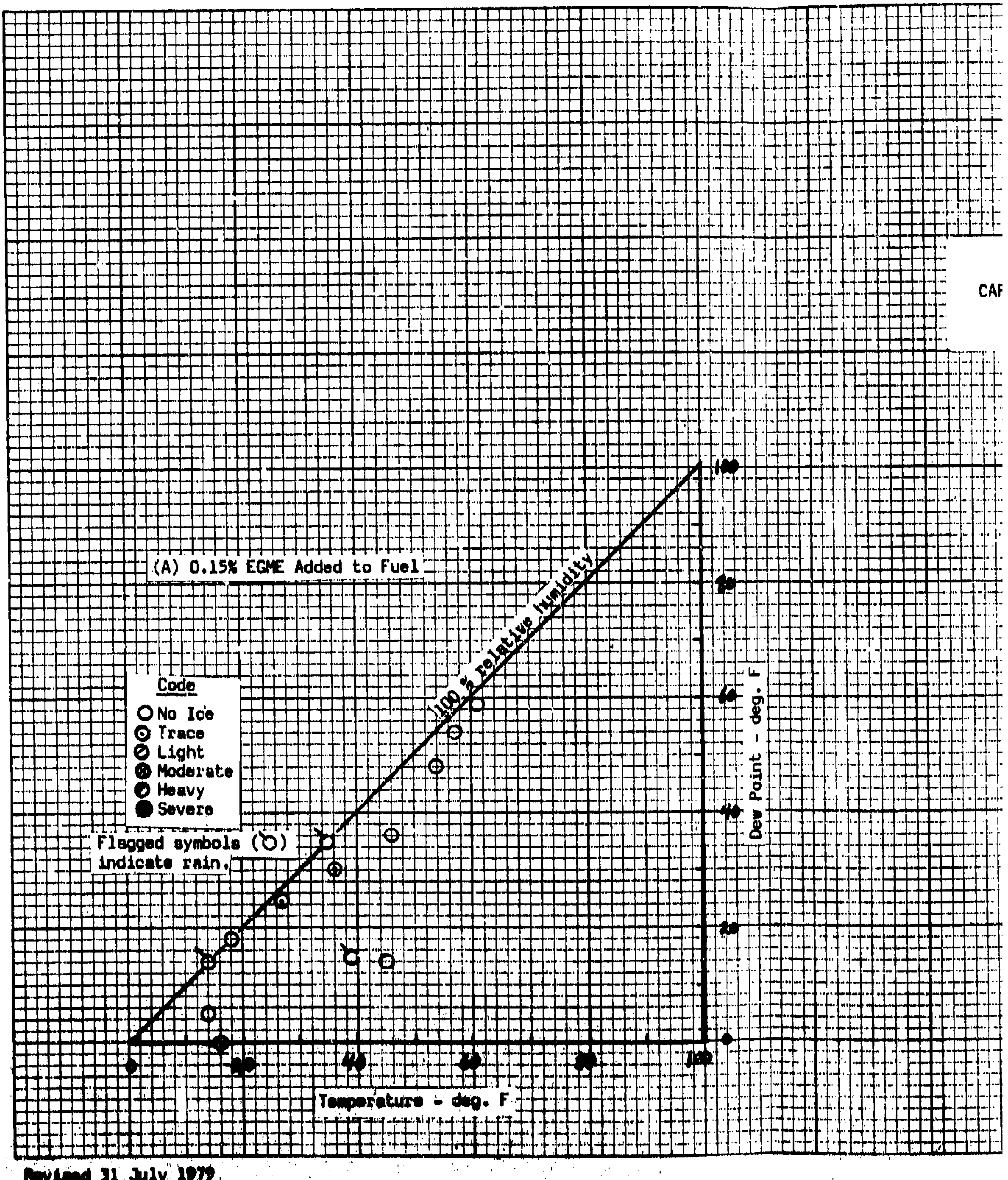
High Power	Throttle greater than 2 units. Two units corresponds to a power of 73% at 3000 ft.
Medium Power	Throttle position of two units or less, but greater than 1.5 units. A setting of 1.5 units corresponds to 60% power at 3000 ft.
Low Power	Throttle position of 1.5 units or less. The approximate minimum throttle setting used was 1.25 units.
Descent Power	Power used in a normal descent to a landing (see descent profile). The throttle was not held fixed, nor were the actual positions recorded.

The scale of units was such that a closed throttle was zero units and a full throttle was 3.5 units.

The effects of mixture and engine speed were ignored during most of the testing.

Effect of EGME Addition -- Normal Cruise

The results of the carburetor icing tests are summarized in Figures 2 through 4. Figure 2 shows the results for high cruise power, Figure 3 shows the results for medium power, and Figure 4 shows the low power results. Each figure shows the data for the engine operated with 0.15% EGME added to the fuel and the data for the control engine separately. The vast majority of the data points are correlated -- the rates were measured on the two engines simultaneously. In fact, every point on the EGME-added sub-figure has a corresponding point on the control sub-figure.



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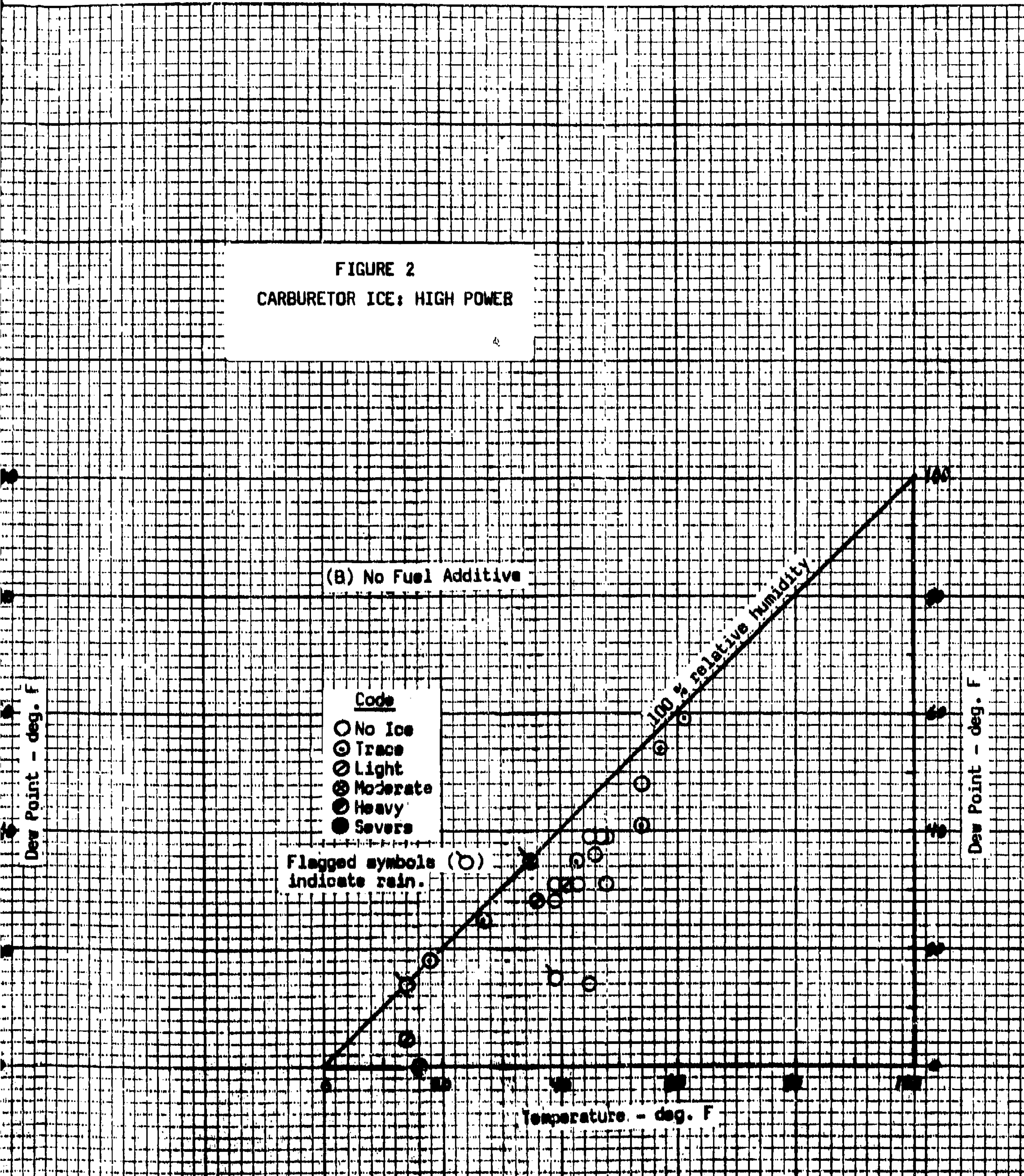

FIGURE 2
CARBURETOR ICE: HIGH POWER

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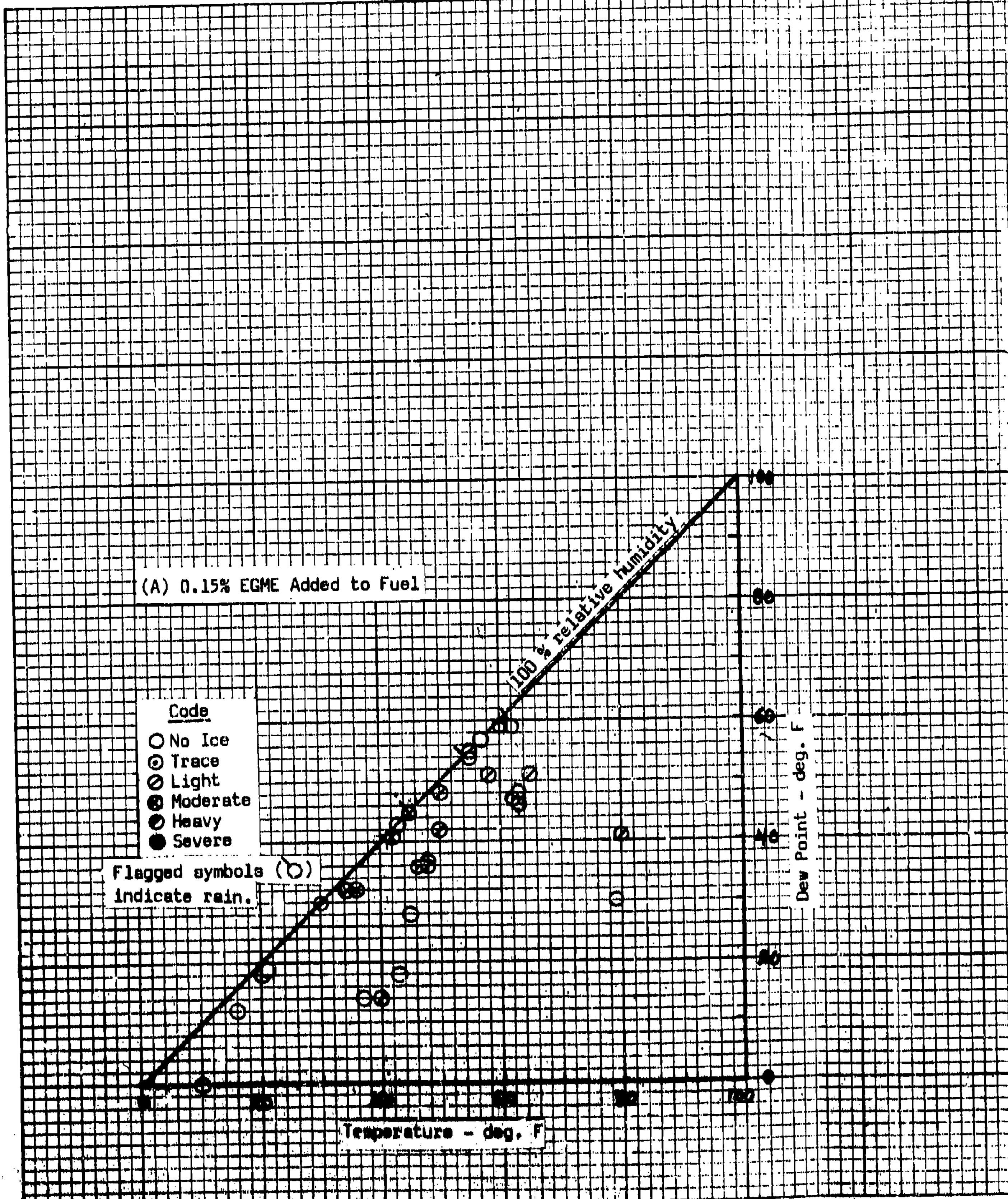

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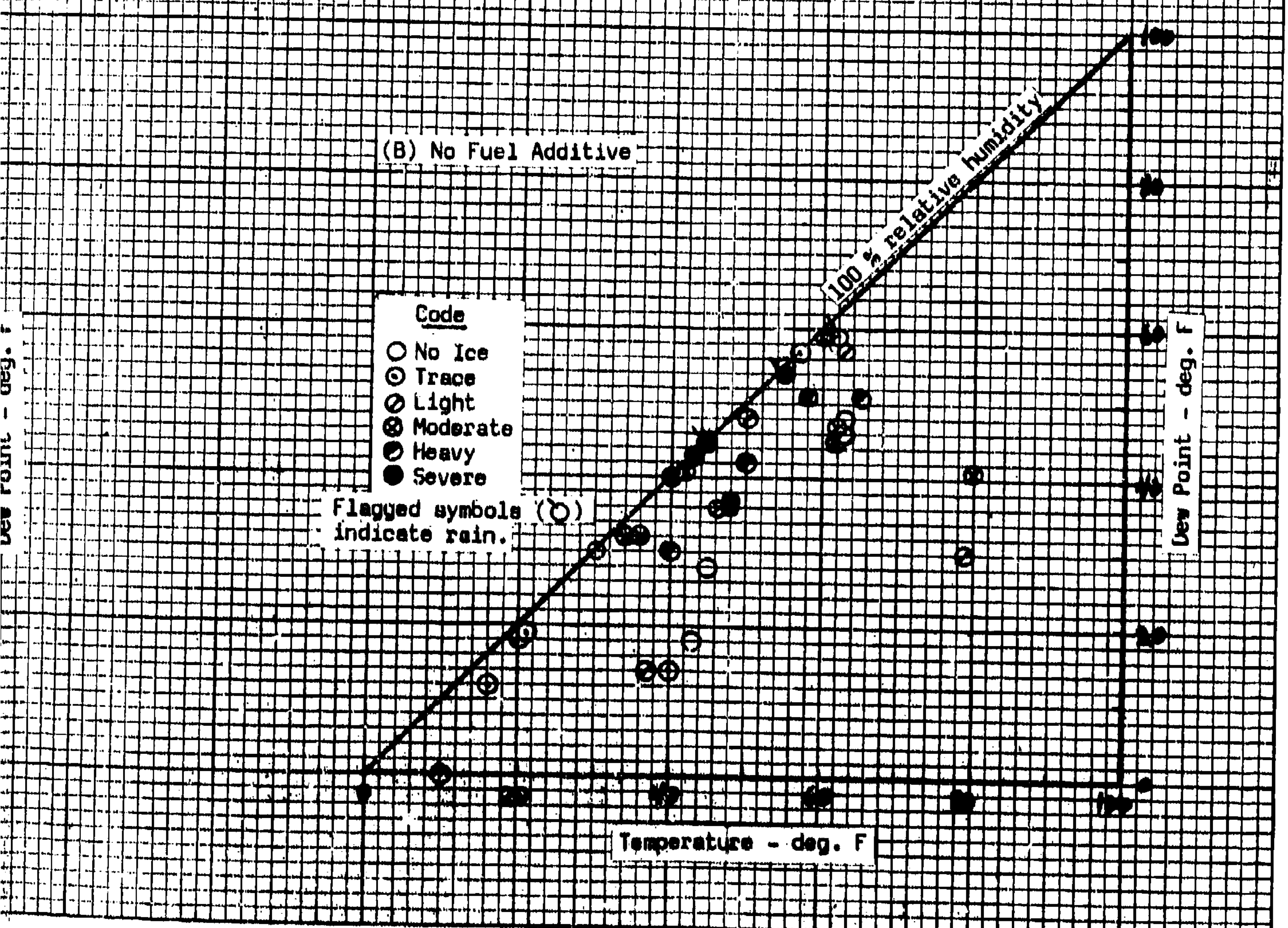
FIGURE 3

CARBURETOR ICE: MEDIUM POWER



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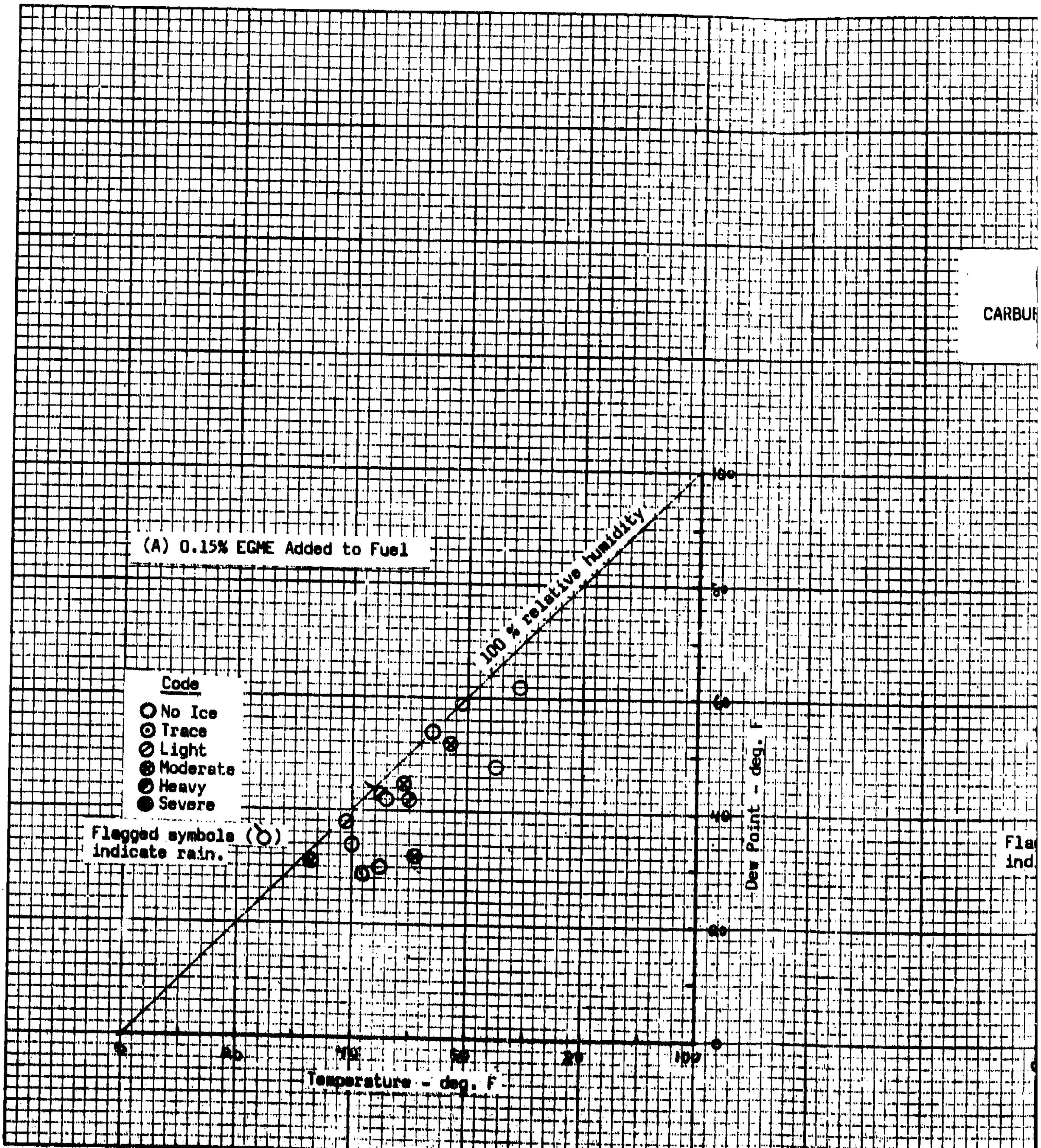

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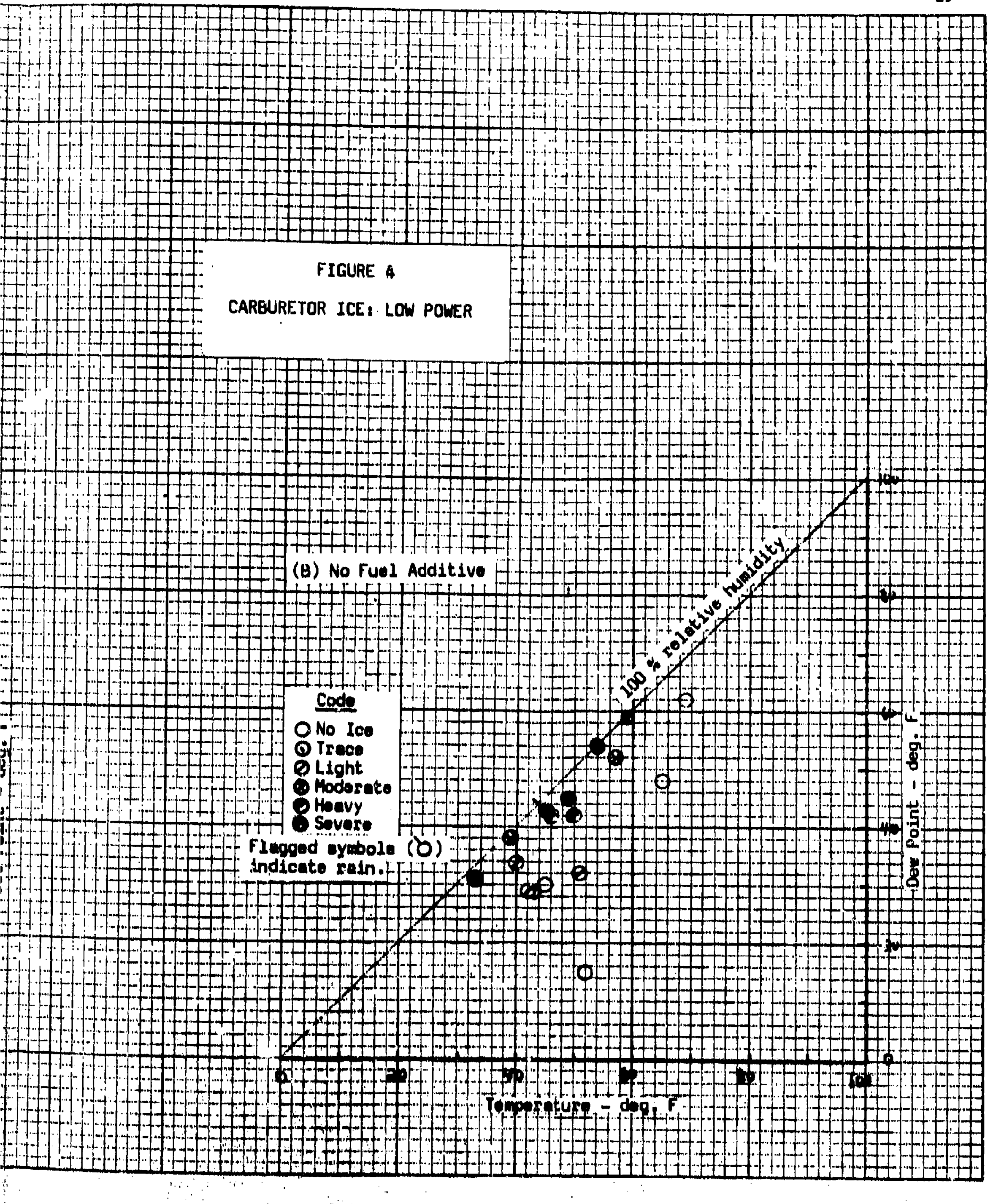


FIGURE 4

CARBURETOR ICE: LOW POWER

There are some points for the control case where no data was obtained for the EGME added case. These points correspond to data taken with both engines operating on straight gasoline or a reduced concentration of EGME. Figure 2 has more of this uncorrelated data since many of the early flights were made without the addition of EGME and were made at 75% power to break in the new engines.

High Cruise Power. As can be seen in Figure 2, the likelihood of encountering severe carburetor icing is quite small at high power settings even without EGME added. The worst degree of icing encountered was "moderate" for the control engine and "trace" for the test engine (with EGME).

Medium Cruise Power. As the throttle is operated more and more in closed position, the likelihood of encountering carburetor ice is greatly enhanced. This is evident in Figure 3 from the greater extent of icing in terms of temperature and dew point. At the same time, the maximum severity of the icing is increased. For the non-EGME case, the worst case of icing was "severe." The maximum rate of icing found was 38.6 inches per hour. For the test case with EGME added to the fuel, the worst case of icing was "moderate," with a rate of 8.2 inches per hour.

Low Cruise Power. The limited amount of data did not show any significant difference between the low and medium power settings. As can be seen in Figure 4, the maximum severity was still "severe" for the control case, and "moderate" for the test case. The rates corresponding to these worst cases were 38.0 and 9.2 inches per hour. There was an indication that the region of severe icing was slightly more extensive for the low power case.

Overall Reduction in Rate. On the average, the rate of carburetor icing was much less with EGME added to the fuel. The rate of the protected engine was two percent of the rate for the unprotected engine for the high cruise power case. At medium power, the relative rate was 19% for the protected engine; and at low power the protected engine ices at a rate of 26% of the protected engine.

Effect of EGME Addition -- Descent Power

Figure 5 shows the results of the carburetor ice encounters during approach and landing. Because of the non-steady-state character of the profiles, the actual rates and environmental conditions are less exact than the steady-state data previously discussed. The worst case of icing for the control fuel case was "severe." In this instance, the control engine failed during an instrument approach and a single-engine landing was made. The worst case of icing for the EGME-added engine was "heavy," with an actual power loss of 1.2 inches of manifold pressure.

While the descent profile was less exact in defining the environmental conditions and in measuring the rates of ice formation, it did have the not inconsiderable advantage of producing correlated data whereby each data point allowed a direct comparison of the test engine and the control engine. On the average, the rate of icing was forty percent with EGME of that without EGME.

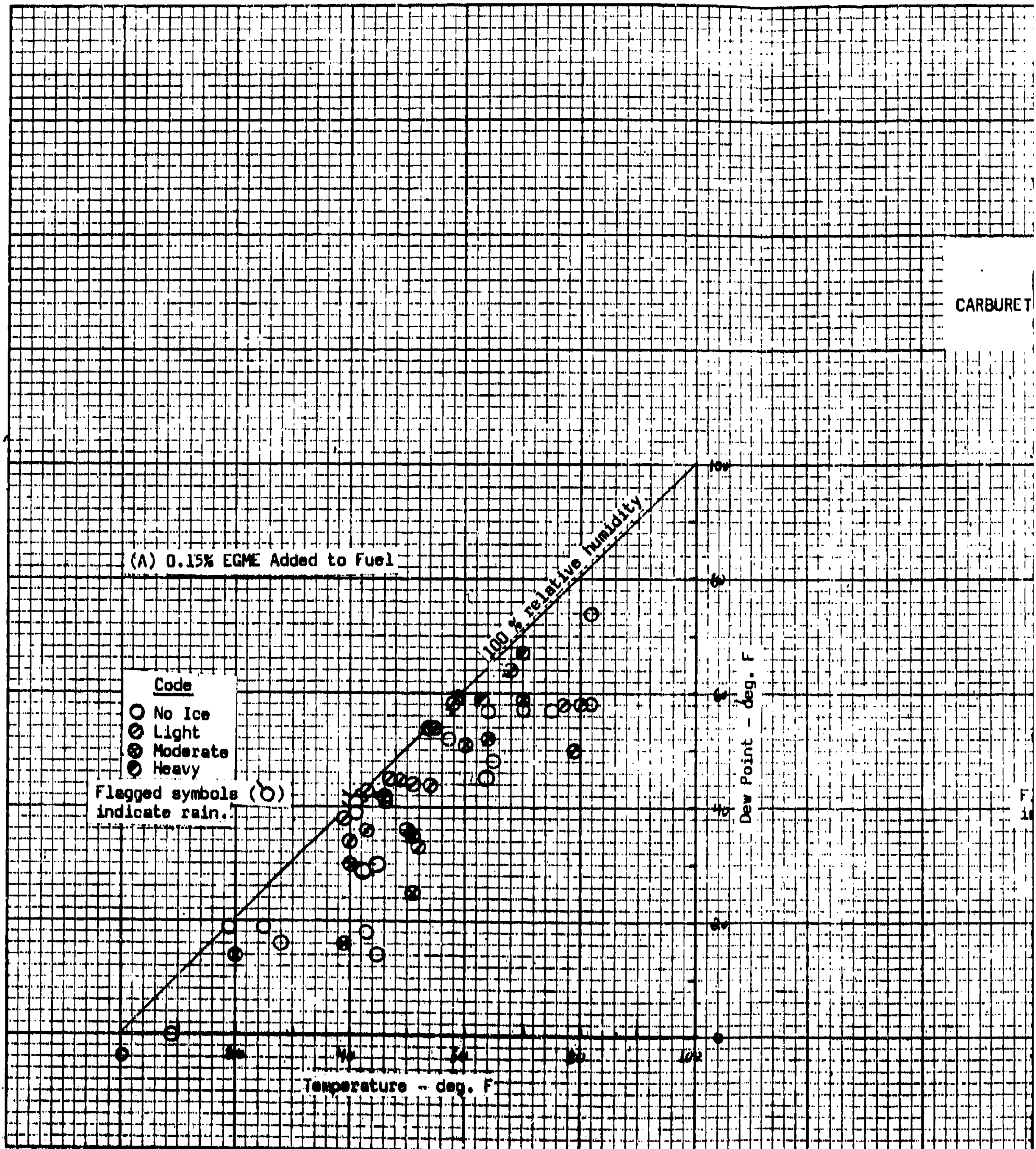
The effect of EGME appeared to be somewhat more sensitive to the specific environmental conditions during the descent profile. There were certain regions in the temperature-dew point plot where the icing was worse with EGME added. This is shown in Figure 6.

As can be seen in Figure 6, there is a region of the temperature-dew point plot around T=60F and DP=60F, where the EGME appears to increase the icing during the descent. There is a region around a dew point of 10 to 15 F where this may also be true. In both of these regions, the limited data available shows an increase in icing with EGME added to the fuel. There is also a region near 50 F where the icing rates are the same.

Effect of EGME Addition -- Non Optimum Concentration

Three encounters with carburetor ice were made with the concentration of EGME intentionally reduced to about two-thirds of the optimum

CARBURET



Revised 31 July 1979

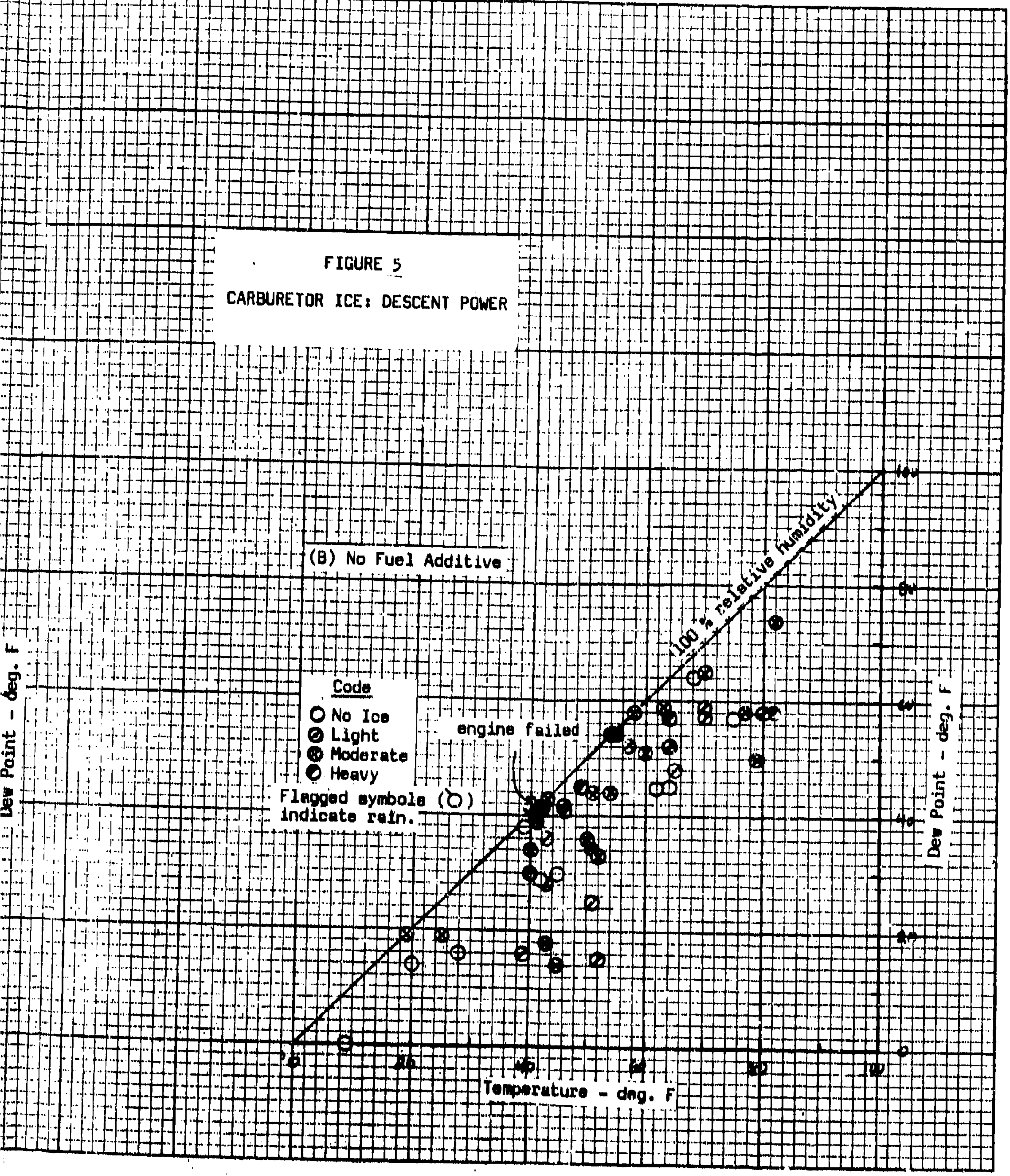
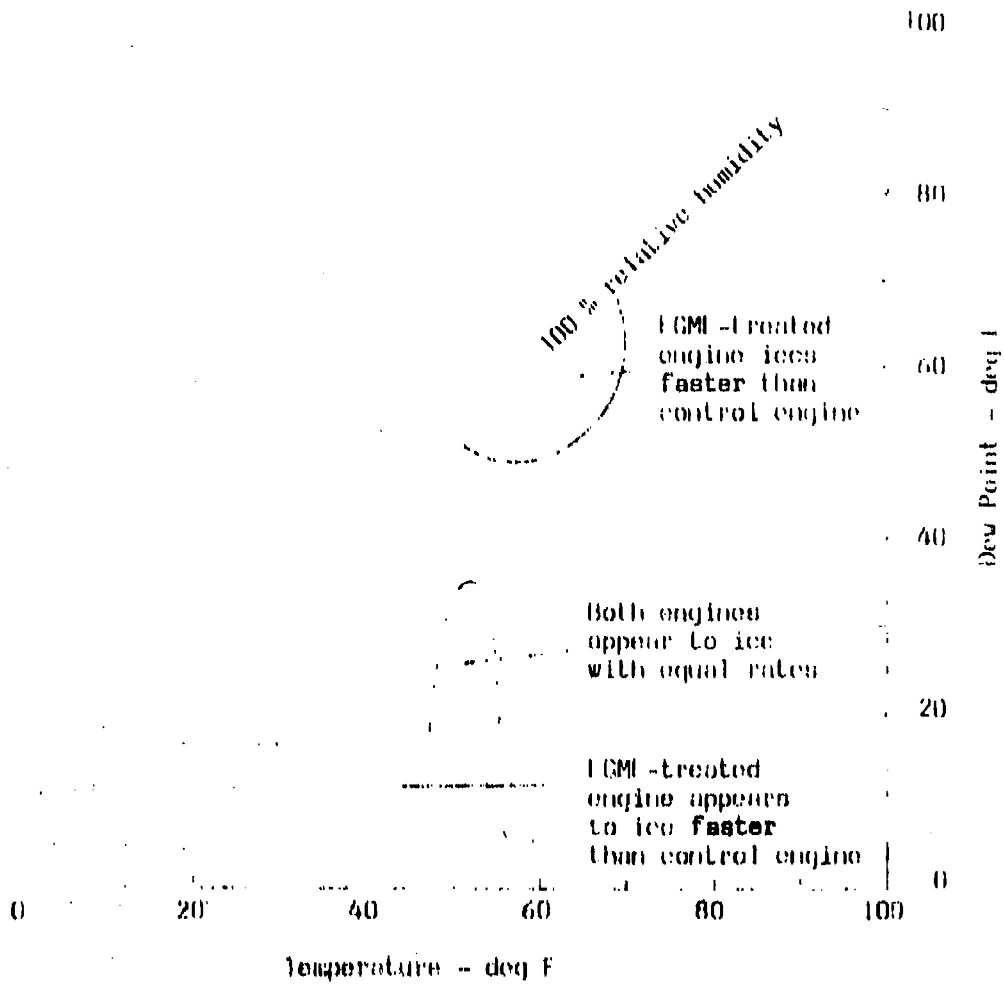


FIGURE 5

CARBURETOR ICE: DESCENT POWER

FIGURE 6

CARBURETOR ICE: DESCENT POWER



value of 0.15%. Twice the concentration was 0.12% and once it was 0.10%. The data obtained with this substandard concentration has not been included with the previous data, but is listed in Table IV.

It should be mentioned that the while the normal concentration of EGME in the test fuel was 0.15% (volume percent), the actual concentration varied from 0.13% to 0.17% because of errors in mixing the additive from the aerosol cans.

Effect of EGME Addition -- De-Icing Capability

On several occasions, after carburetor ice was allowed to form in the carburetor of one of the engines, the fuel supply was switched from the control (EGME-free) fuel to the fuel containing EGME. Table V shows the results of this procedure. It would appear that EGME in the fuel can be used as a de-icer as well as an anti-icing additive. It is not clear, however, exactly how this would be managed in practice.

Comparison of the Icing Characteristics of the Two Engines

One question that arises when two engines are used, one for a control and one for a test engine, is "How do they compare under identical control conditions?" Since the early part of the test flying was performed under identical conditions (using straight aviation gasoline in both engines), chiefly to refine the test procedures and to break in the newly remanufactured engines, this comparison was obtained. In addition, several times during the testing, the left engine was operated from the right tank using crossfeed, and carburetor ice data was obtained.

A comparison of the encounters with both engines operating on stock fuel shows than the average rate of icing for the left engine was 1.87 times that of the right engine. The correlation between the two rates was 0.99. Thus, if anything, the engine used to test the EGME was slightly more prone to carburetor ice than was the control engine.

EGME Concentration	Environmental Conditions			Measured Icing Rates		Predicted Icing Rate 0.15% EGME Added
	Temp.	D. P.	Power	Test Engine	Control Engine	
0.12%	40 F	40 F	Medium	Trace	Heavy	Moderate
0.12%	43 F	29 F	Low	None	Light	Light
0.12%	52 F	15 F	Low	None	None	None
0.12%	43 F	29 F	Descent	Moderate	Moderate	Moderate
0.12%	52 F	15 F	Descent	Moderate	Light	Light
0.08%	62 F	45 F	Medium	Trace	Moderate	None
0.08%	40 F	40 F	Medium	Light	Moderate	Moderate
0.08%	62 F	45 F	Descent	Heavy	None	Moderate

TABLE IV

EFFECT OF REDUCED EGME CONCENTRATION

Flight Conditions			Carburetor	Monifold Pressure		Engine
Temp.	D. P.	Power	Icing Rate	Lost	Regained	
63 F	54 F	Medium	7.6 in/hr (Moderate)	1.9 in	1.8 in	Left
63 F	54 F	Medium	4.0 in/hr (Light)	1.0 in	1.0 in	Right
58 F	51 F	Medium	34.8 in/hr (Severe)	3.9 in	1.9 in	Left
57 F	52 F	Low	12.0 in/hr (Heavy)	2.3 in	2.3 in	Left
54 F	54 F	Low	21.6 in/hr (Severe)	1.8 in	1.8 in	Right

TABLE V

USE OF EGME AS A DE-ICER

Comparison of Other Operating Variables

Several other operating parameters, while not listed in the objectives of the program, still warrant mentioning.

Altitude. There was a correlation of carburetor ice formation with altitude. Very little ice was encountered above six thousand feet. This is almost certainly the effect of the wide open throttle settings necessary to maintain power at the reduced air densities.

Mixture. Five carburetor ice encounters were made with both engines operating on stock gasoline, but with one engine leaned and the other enriched. As discussed earlier, the early NACA work by Coles (3) and the reports by Diblin (6) do not agree on the effect of mixture. While the sample size is too small to justify any statistical test, the engine operated with a rich mixture had an icing rate approximately thirty-nine percent greater than the engine operated with a lean mixture.

Throttle Motion. On one occasion, after carburetor ice had formed in the right engine and power had decreased several inches, the throttle was closed and reopened to the same index. The engine recovered almost all of its "lost" power with this motion. Probably the movement of the throttle broke off the ice that had formed.

Carburetor Air Temperature Gauges. The carburetor air temperature gauges did not appear to be especially valuable in determining if the conditions were right within the carburetor for the formation of carburetor ice. For the most part, the temperatures were in the range of -4 to +4 degrees C and seemed to be more a function of throttle position than of outside air temperature. Several times, carburetor ice formed with indicated temperatures well outside the yellow band of -10 to +5 degrees C.

Exhaust Gas Temperature Gauges. The EGT variations did point out changes in the mixture as carburetor ice formed. Quite often this happened at icing rates too slow to detect easily with the manifold pressure gauge. However, the minute to minute variations of the EGT and the difficulty in recording the many temperatures necessary to get a trend would seem to rule out the EGT as a tool for carburetor ice detection.

Variations within the Atmosphere. Most of the data was collected while flying within a very small portion of the atmosphere. Nevertheless we did note that there were temperature, dew point, and icing rate variations on a fairly small scale. Based on subjective observations, we do not feel that the average pilot would remain very long in conditions conducive to carburetor ice without flying out of these conditions. (The obvious exception would be instrument rated pilots.) The conditions favorable for carburetor ice are more common than are commonly believed by pilots; however, few of them are exposed for a significant length of time at any one exposure. Thus, they may well miss detecting the loss in power.

Several times, data was lost during flight because the airplane flew into conditions in which the ice was lost. This was noted by a slow drop in power, but before the ice detection could be confirmed by applying carburetor heat, the engine spontaneously regained its power. Almost assuredly, these drops and regainings of power were caused by carburetor ice; nevertheless, they could not be confirmed as such. These conditions were noted as "trace" if no additional data could be obtained on that flight.

DISCUSSION

Several areas warrant further discussion. These areas are the general topic of EGME's effectiveness, the techniques for obtaining and detecting carburetor ice, and some unresolved points concerning EGME and carburetor ice.

Effectiveness of EGME

Based on the results of the testing, the use of EGME appears to be very attractive considering its effectiveness during the cruise portion of flight. While it does not totally eliminate the formation of carburetor ice, it does greatly reduce both the maximum intensity and the extent of the conditions in which carburetor ice will form. In cruise conditions, the use of EGME appears to completely eliminate both heavy and severe carburetor ice.

If we put this in other terms, the predicted time to engine failure from carburetor ice (with EGME added) is of the order of two hours. The typical VFR pilot will not be likely to be flying in conditions conducive to carburetor ice for longer periods. Therefore, we consider it highly likely that EGME would prevent VFR carburetor ice accidents during the cruise or higher power portions of flight. This would not be as true for the IFR pilot, who might well spend two hours in the more intense regions of the temperature-dew point plot.

The effectiveness of EGME appears to become less at the lower power settings (more restricted throttle openings). At high power, the EGME protected engine had an average icing rate of 2% of the unprotected engine. As the throttle was operated more and more in the closed position, this rate increased relative to the unprotected engine. While it never did reach the average of the unprotected engine, the effectiveness of

EGME at idle or near idle power is not as clear. In particular, it would seem that conditions close to 40 F and near saturation generate ice equally with or without EGME (at descent power). More interesting (and more critical) is the observation that some conditions actually may promote ice formation with EGME added to the fuel. These conditions are 60 F and near saturation or temperatures of the order of 20 to 40 F and dew points of 10 to 15 F. Nevertheless, on the whole, the addition of EGME does seem to have an overall beneficial effect on the prevention of ice during the descent, but not as great as during cruise.

Figures 7 and 8 show the overall summary of the flight test data fairing in the regions of light, moderate, and heavy icing both with and without EGME added to the fuel.

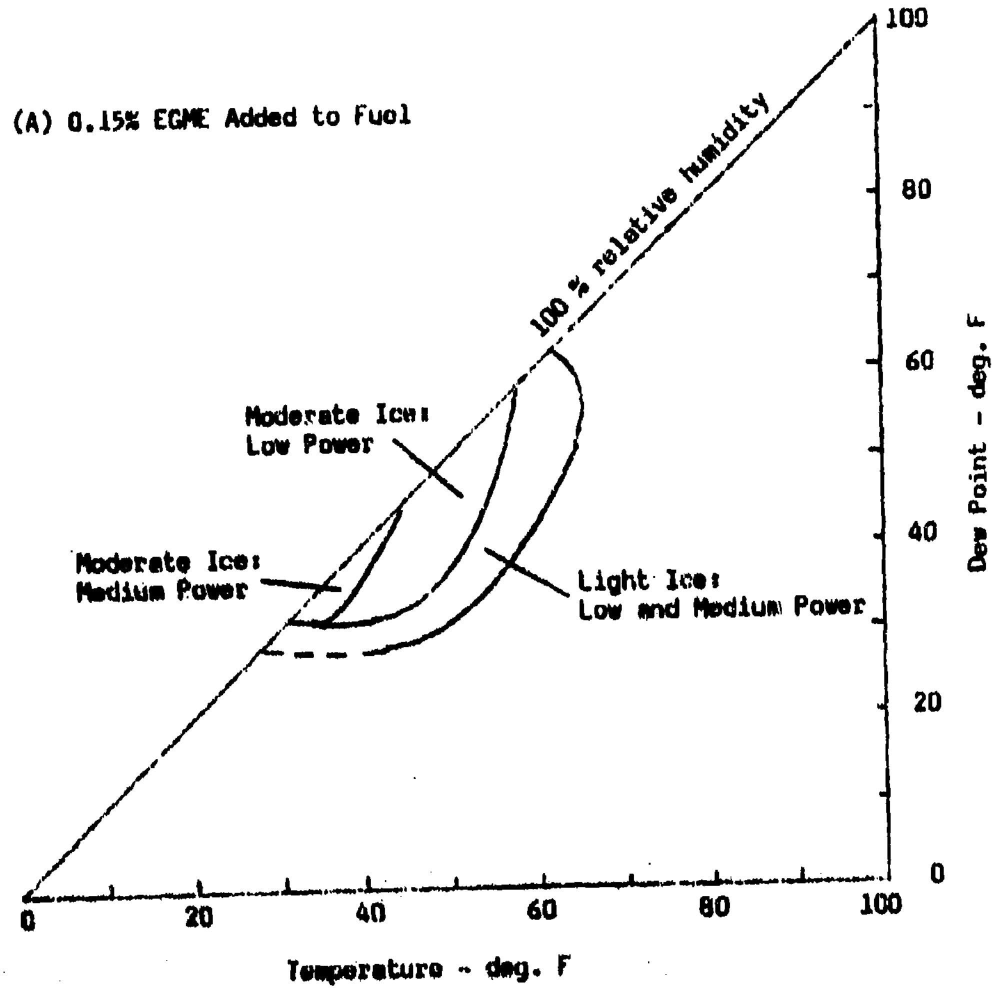
Carburetor Ice Techniques

Based on a now considerable experience in flying engines in conditions that generate carburetor ice, several comments regarding pilot techniques can be offered.

Ice Detection. The best available instrument to detect carburetor ice appears to be the airspeed indicator. If the airplane is flown so as to maintain a constant altitude, then the most sensitive instrument and the one most in the pilot's field of view is the airspeed indicator. Many times during the testing, a considerable amount of airspeed was lost (ten to twenty knots) before more than one inch of manifold pressure drop was noticed.

The second best instrument would be a manifold pressure gauge. Granted that neither the airspeed nor the manifold pressure gauge measures ice formation, either will serve to show the power lost by the engine(s).

The carburetor air temperature gauge did not appear to be sensitive enough to show appreciable variations within the carburetor, nor did it accurately show freezing conditions. A naive pilot might actually be

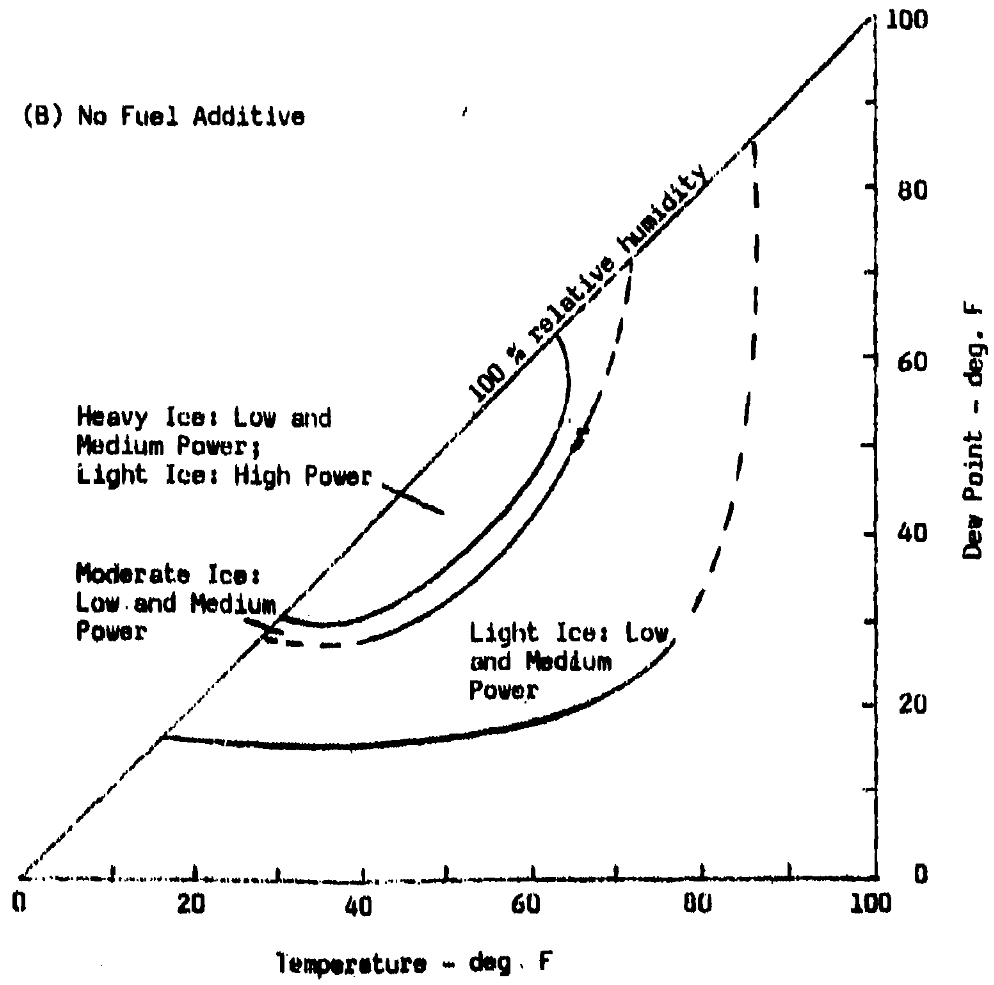


(A) 0.15% EGME Added to Fuel
100 % relative humidity
Moderate Ice: Low Power
Moderate Ice: Medium Power
Light Ice: Low and Medium Power
0
20
40
60
80
100
Temperature - deg. F
Dew Point - deg. F

FIGURE 7

CARBURETOR ICE: CRUISE POWER

SUMMARY OF FLIGHT TEST RESULTS



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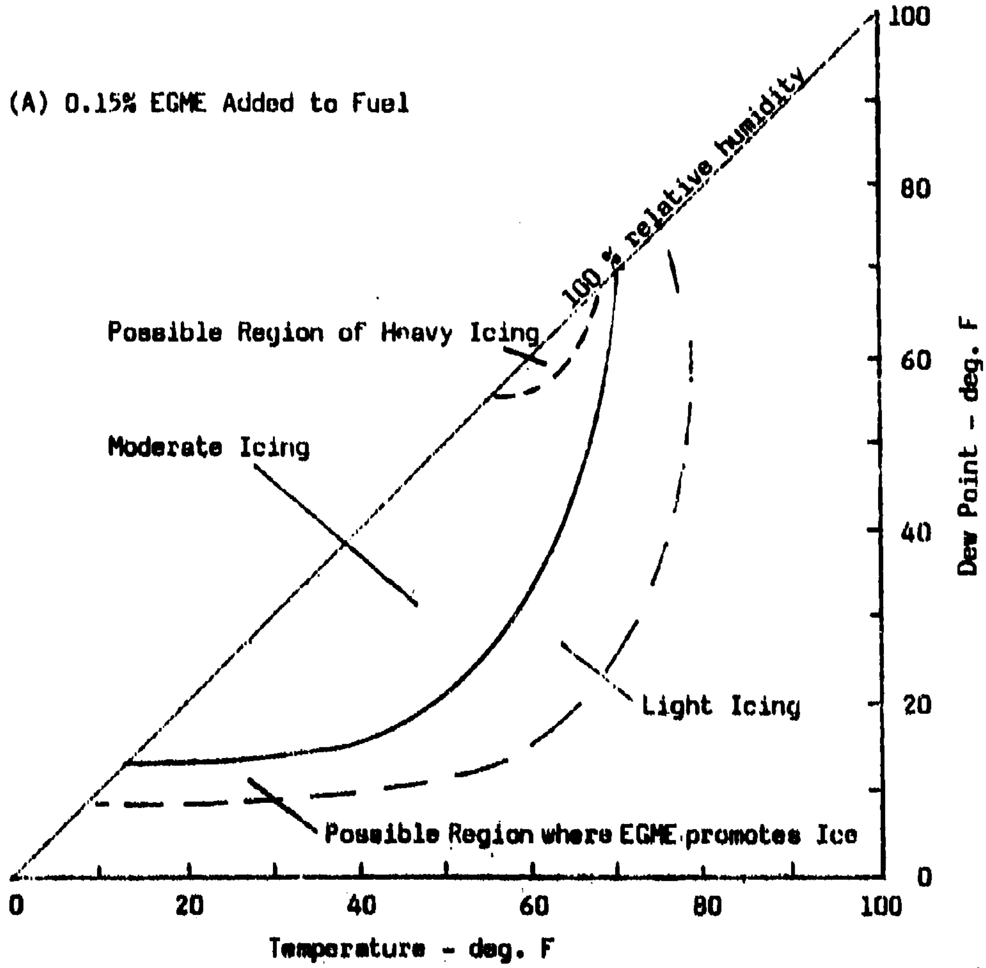
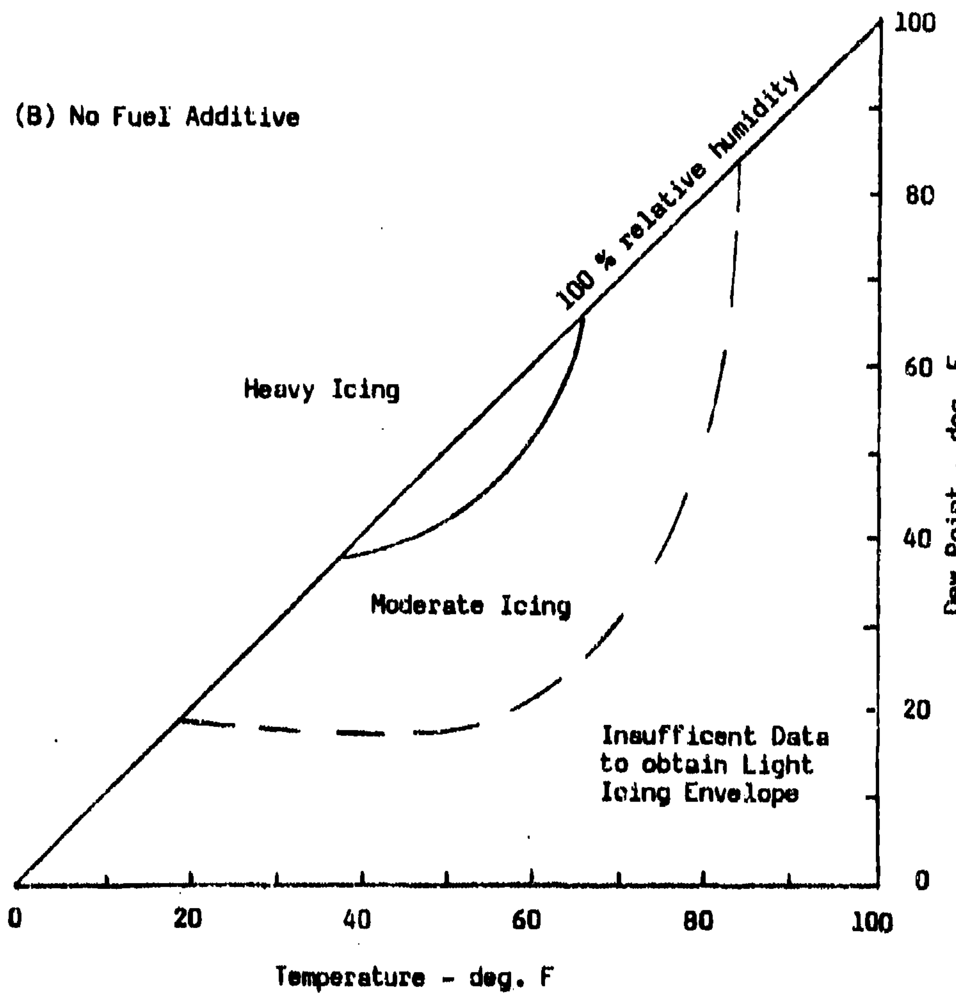

(A) 0.15% EGME Added to Fuel
100 % relative humidity
Possible Region of Heavy Icing
Moderate Icing
Light Icing
Possible Region where EGME promotes Ice
0
20
40
60
80
100
Temperature - deg. F
Dew Point - deg. F

FIGURE 8

CARBURETOR ICE: DESCENT POWER

SUMMARY OF FLIGHT TEST RESULTS



2

lulled into complacency by temperatures in the green as ice was forming within the carburetor. The mixture analyzer (multiple EGT) did show variation in the mixture as ice was forming; however the complexity of such a device would tend to rule it out as an ice detector. It does have several other uses, however.

In the absence of a proven carburetor ice detector, the manifold pressure gauge (or the airspeed) would be the preferred carburetor ice detector, with the multiple EGT a distant second.

Recovery from Carburetor Ice. Quite often, after a considerable amount of carburetor ice had formed, the amount of heat was not enough to rapidly melt the ice for a few seconds. Several times these few seconds developed into two or three minutes. This was clearly the result of insufficient power available to generate the heat necessary to warm the incoming air. The solution to this problem is two-fold. Opening the throttle while applying heat may make the difference between a slow or non-existent recovery and a fast recovery because of the additional power and heat available. Throttle movement may also break off the ice that has formed.

A second solution is to keep the engine parts warm by periodically "clearing the engine" by brief additions of power. Both the increased heat through the carburetor heater and the throttle movement will prevent a significant accumulation of ice and will also keep the metal parts hotter.

Addition of EGME "By the Can." The EGME in this study was added during aircraft refueling using an aerosol can. While only one analysis was seriously out of tolerance, the concentration did vary from tankful to tankful. It would seem reasonable to expect that typical general aviation pilots and line personnel would not be as careful in the addition of the additive (it required the use of a stopwatch and a pocket calculator to monitor the concentration). Very likely, if Prist(R) or similar cans are used widely in general aviation piston fuel, then some over-concentrations will result. It is not clear what the effects of these high concentrations will be on engines or fuel systems. Therefore, we cannot support the use of EGME addition into the tank directly by the pilot or line personnel on a wide basis. If aerosol spray cans with flow rates appropriate for gasoline delivery are available, we may modify this statement.

Unresolved Points in the Testing

Three aspects remain unresolved in the flight testing of EGME as an anti-icing additive. These are: the overall descent data is incomplete, the effect of non-optimum concentrations should be looked at, and the long term effects of EGME have not yet been examined.

Descent Data. The descent data (Figures 5 and 6) has raised some questions concerning the effectiveness of EGME in the regions near 60 F and near saturation and at low dew points (10 to 15 F). Part of this problem is the imprecise nature of the descent profile. The descent profile was not an original part of the flight test plan, but was added part way through the program to obtain valid descent data. Because of its imprecise nature (environmental data cannot be maintained, nor can steady-state profiles be flown), more data samples are required to draw conclusions than for the steady state cruise conditions.

The descent profile as flown in these tests was somewhat varied by ATC constraints. Because of the low priority of this data, no effort was made to coordinate and fly consistent profiles. Therefore, any follow-on testing should emphasize the need for repeatable descent profiles. This testing will always be less precise than cruise testing, however.

No explanation can be advanced for the apparent increased tendency of engines operated with EGME to ice up at conditions approaching T=60F.

The low temperature enhancement of carburetor icing can be explained by the lowering of the freezing point of water by EGME. If the freezing point of the condensing water in the carburetor is lowered to about 15 F, then we might expect the carburetor icing to be worse as the dew point approaches that value. The non-EGME engine will have ice crystals condensing out of the air -- too cold to freeze to the carburetor structure. The engine operating with EGME-treated fuel will have ice/water condensing. While this explanation is more of a rationalization, nevertheless the problem should be examined more carefully before mandating the addition of EGME to aviation gasoline.

Non-Optimum Concentration of EGME. It has been reported that the actual concentration of EGME in turbine fuel may be reduced to one-third the value at the refinery because of leeching out by ambient moisture (11). If this is true, then additional data should be taken with the EGME concentration reduced to this value. The preliminary data taken with about two-thirds the optimum concentration indicates that this level of EGME will still be effective during cruise. The choice of two-thirds of the nominal concentration was dictated by circumstances. Following flights with nominal concentrations, the EGME was diluted by topping off with additional fuel and no EGME. The resultant concentrations were as shown in Table IV.

Long Term Effects of EGME. Two areas of concern with the long term use of EGME are the loss in concentration as the fuel is stored in an aircraft gas tank and the effect of continued use of EGME in the fuel for extended periods of time, both service time and calendar time.

Many general aviation airplanes spend a great deal of time parked, not flying. In particular, many do not fly at all during the winter months. A serious question is "what happens to the EGME in such a case?" Does the concentration remain high enough to be effective upon leaving storage? Does the stored fuel react with the fuel tanks in any fashion?

A second, more serious question concerns the effect of any fuel additive or change to an engine operated over a long period of time. Will the addition of EGME have any deleterious effect on the engine for a period of time approaching the overhaul life. In view of the problems of operating engines on low-lead 100 octane gasoline, which only appeared after several hundred hours of operation, this question cannot be passed over lightly.

CONCLUSIONS

The addition of ethylene glycol monomethyl ether (EGME) to aviation gasoline greatly reduces the formation of carburetor ice during cruise power conditions. Both the extent of conditions producing ice and the maximum severity of the ice formation are reduced. This is more pronounced at the higher power settings. The use of EGME should prevent virtually all cruise or climb carburetor ice accidents for VFR pilots. Since over sixty percent of carburetor ice accidents occur during these phases of flight, this would be no small benefit.

There do appear to be certain environmental conditions which make the use of EGME less favorable during descents. Certain dew point/temperature combinations produced more ice with EGME-treated fuel than with stock aviation gasoline. These conditions should be examined further before drawing any conclusions regarding the effectiveness of EGME in preventing carburetor ice during descent conditions.

The use of aerosol spray cans (with flow rates designed for turbine airplanes) is not a satisfactory means of adding EGME to the fuel of general aviation piston powered airplanes. While it is suitable for limited testing, variations in the concentrations and the need to carefully monitor the addition with a stopwatch and to analyze the gasoline periodically make this technique impractical for most operators.

Carburetor air temperature gauges do not appear to be a reliable means of monitoring the carburetor for conditions conducive to carburetor ice formation.

RECOMMENDATIONS

1. Subject to satisfactory results from the tests described in recommendations 2 and 3, the addition of ethylene glycol monomethyl ether (EGME) to aviation gasoline is recommended.

2. The effectiveness of EGME in preventing carburetor ice during descent power flight should be more thoroughly investigated in those environmental conditions where the data to date indicates a possible increase in icing with EGME-treated fuel.

3. The long term effect of EGME on aircraft and engine systems should be examined over a period of operations approaching the overhaul cycle.

4. The effectiveness of EGME at one-third the nominal concentration should be investigated during cruise power flight and during descents.

5. The storage of EGME-treated fuel should be examined with particular regard to long term storage in aircraft fuel tanks.

6. The effectiveness of commercially available carburetor ice detectors in providing adequate pilot warning of ice formation should be examined. This testing could be conducted in parallel with the tests in recommendations 2 and 4 above.

ACKNOWLEDGEMENTS

We wish to express our appreciation to two organizations which made the flight test operations much easier. The Dayton Approach Control Facility provided the highest degree of cooperation in allowing the test flights to operate IFR for extended periods in the terminal area with a minimum amount of interference with the taking of data. The line personnel of Springfield Aircraft and Maintenance Corporation put up with a fair amount of trouble during refueling operations involving adding EGME to the fuel of one tank and requiring the use of a stopwatch to time the flow of the additive. We certainly appreciate the help and cooperation of both groups.

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FLIGHT TEST RESULTS

OF THE USE OF

ETHYLENE GLYCOL MONOMETHYL ETHER (EGME)

AS AN ANTI-CARBURETOR-ICING FUEL ADDITIVE

APPENDIX

-Data Summary-

CONDITIONS				LEFT ENGINE							RIGHT ENGINE					
T	DP	WX	ALT	%EGME	TP	CTT	ΔEGT pk	ΔEGT gc	MPL	RATE	TP	CTT	ΔEGT pk	ΔEGT gc	MPL	RATE
14	5		5000	0.18	3	-10	+10	-40	nil	zero	3	-8	+50	+50	1.5	1.0
14	14	CR-	9800	0.15	3½	-8	0	+10	nil	zero	3½	-8	-35	-70	0.2	0.2
16	0		14500	0.16	3¼	0	-5	+20	nil	zero	3¼	+2	-20	-20	nil	zero
18	18	C	12800	0.14	3½	-2	-	-	nil	zero	3½	+2	-	-	nil	zero
27	25		5000	0.18	3½	-10	+10	-40	0.2	0.2	3½	-8	+50	+50	1.5	1.0
35	35	CR	6000	0.15	2½	0	-	-	nil	zero	2½	+2	-	-	5.5	15.7
36	28		4000	zero	2¼	-8	+65	+70	1.0	0.7	2¼	-4	+85	+100	1.5	1.0
36	30		9400	0.15	3½	-6	+10	+30	0.1	trace	3½	-4	+5	+30	0.2	0.5
39	15	R	9000	0.13	3½	0	0	-5	nil	zero	3½	+2	-	-	nil	zero
39	31		4000	zero	2½	-4	+5	-10	nil	zero	2½	-2	-	-	nil	zero
41	31		5000	zero	2½	0	+10	+10	1.3	0.9	2½	+2	+10	+15	1.5	1.1
43	31		7500	zero	3½	+4	-15	-15	nil	zero	3½	+5	-5	+20	nil	zero
43	35		3300	zero	2-1/8	-2	-45	-45	0.1	trace	2-1/8	0	0	-20	0.2	0.1
45	14		8300	0.13	3½	-	-	-	nil	zero	3½	-	-	-	nil	zero
45	39		7100	zero	3½	+4	-25	-25	nil	zero	3½	+6	-10	+20	nil	zero
46	36		4800	0.15	2¼	-4	+35	+35	nil	trace	2¼	-2	+55	+90	0.2	0.3
47	39		6200	zero	3½	+4	-5	+15	nil	zero	3½	+8	+15	-15	nil	zero
48	31		5500	zero	3	0	-	-	nil	zero	3	+2	-	-	nil	zero
48	39		5000	zero	2-5/8	+2	-15	-15	nil	zero	2-5/8	+4	+20	-20	nil	zero
54	41		4000	zero	2¼	+5	-20	+60	0.5	0.4	2¼	+5	-5	-25	nil	zero
54	48		3000	0.13	3	+8	-	-	nil	zero	3	+10	-	-	nil	zero
57	54		4950	0.14	2-3/4	+2	-15	+30	nil	zero	2-3/4	+5	-10	-80	0.1	trace
61	59	C	4900	0.14	2½	+2	+5	+20	nil	zero	2½	+4	+60	+95	nil	trace

TABLE A-1

FLIGHT TEST DATA

HIGH POWER

CONDITIONS				LEFT ENGINE							RIGHT ENGINE					
T	DP	WX	ALT	%EGHE	TP	CTT	ΔEGT pk	ΔEGT gc	MPL	RATE	TP	CTT	ΔEGT pk	ΔEGT gc	MPL	RATE
10	0		5000	0.16	2	-8	+30	+40	nil	zero	2	-8	+35	+35	nil	zero
16	12	S-	3000	0.14	2	-12	-	-	nil	zero	2	-12	-	-	0.3	0.3
20	18		5000	0.15	2	-14	+30	+30	nil	zero	2	-12	+65	+65	0.5	0.6
21	19		3000	0.15	2	-12	+20	+45	nil	zero	2	-12	+5	+25	0.5	0.3
30	30	C	4000	0.18	1-7/8	-8	-20	-20	0.2	0.5	1-7/8	-8	-5	+30	0.4	1.0
34	32		3000	0.18	1-7/8	-6	+36	+55	1.2	0.9	1-7/8	-8	+75	+110	8.1	5.8
36	32		3000	zero	1½	-4	0	+25	3.7	8.2	1½	-6	-10	+20	7.9	6.4
37	16		3500	0.15	2	-8	+25	+25	nil	zero	1-7/8	-8	-10	+50	0.4	1.6
40	16		3500	0.15	2	-6	0	-15	1.0	0.9	2	-8	+10	+10	0.2	0.2
40	30		3600	0.12	1½	-4	+35	+35	0.2	0.4	1½	0	-	-	5.6	10.8
40	40	C	3800	0.08	1-3/4	-4	-	-	1.2	4.2	1-3/4	-4	-	-	2.5	8.8
42	43		4000	zero	1½	-8	-75	-75	2.3	5.9	1½	-8	-90	-90	3.1	7.7
43	18		1600	0.15	1½	0	+10	-10	nil	zero	1½	0	+20	+20	nil	zero
43	43	C	4000	zero	1½	-8	-	-	4.0	4.3	--	hot	--	--	---	---
43	43	C	3000	0.15	1-3/4	-6	-	-	0.3	0.3	1-3/4	-6	-	-	9.1	21.0
45	28		1600	0.15	1½	+2	+15	-15	nil	zero	1½	+2	+10	-45	nil	zero
45	45	CR	4050	0.14	2	-4	-	-	0.6	1.2	2	-4	-	-	20.0	34.3
45	45	R+	3000	0.15	1½	0	-	-	2.8	6.4	1½	0	-	-	quit	21.0
46	36		2900	0.14	2	-2	-10	-15	0.2	0.2	2	-2	-55	-55	0.7	0.8
48	36		4100	0.16	1½	0	+5	-10	0.5	0.6	1½	0	-35	-50	5.0	6.2
48	37		1600	0.15	1½	+2	0	-15	nil	zero	1½	+2	+20	+45	0.7	0.9
50	48		3000	0.13	2	+4	+5	+10	0.2	0.6	2	+4	-10	-15	0.4	1.1
55	54	R-	4950	0.14	1-3/4	+2	0	+5	0.2	1.1	1-3/4	+5	-45	-80	4.1	22.4
55	55		6000	0.16	1½	-	-	-	0.4	1.5	1½	-	-	-	0.6	2.2
57	57		4000	0.15	1½	+8	+15	+15	nil	zero	1½	+8	0	-10	0.1	trace
58	51		6000	0.16	1½	+5	-5	+15	0.8	2.7	1½	+8	-35	-35	2.4	8.0
58	51		6000	zero	1½	+5	lean mixture		8.9	30.3	1½	+8	lean mixture		2.5	6.5
58	51		6000	zero	1½	+5	rich mixture		5.5	36.9	1½	+8	rich mixture		2.5	12.5
60	59		4900	0.14	1½	+4	-10	-30	nil	zero	1½	+4	-85	-85	1.1	10.5
62	45		2500	0.08	1-3/4	+2	-5	+25	0.2	0.2	1-3/4	+4	-50	-85	7.5	7.0
62	45		3300	0.15	1-3/4	+2	+5	-20	nil	zero	1-3/4	+2	-15	-15	nil	zero
62	59	R-	4100	0.15	1½	+5	+5	+10	nil	zero	1½	+4	-	-	nil	zero
63	46		2500	0.15	1½	+4	-20	-20	nil	zero	1½	+4	-30	-30	nil	zero
63	48	C	3000	0.13	2	+5	-10	+10	nil	zero	2	+6	0	+15	nil	zero
63	57		6000	zero	2	+4	-10	-30	2.2	3.7	2	+4	-45	-45	1.3	3.0
65	51		6000	0.16	1½	+5	-	-	0.5	1.2	1½	+5	-	-	4.2	10.1
79	31		4000	0.15	1½	+5	0	+10	nil	zero	1½	+5	-40	-40	0.9	1.8
80	41		4000	0.15	1½	+4	--	--	1.2	4.2	1½	+4	--	--	2.0	7.0

TABLE A-2

FLIGHT TEST DATA

MEDIUM POWER

CONDITIONS				LEFT ENGINE							RIGHT ENGINE					
T	DP	WX	ALT	%EGME	TP	CTT	ΔEGT_{pk}	ΔEGT_{gc}	MPL	RATE	TF	CTT	ΔEGT_{pk}	ΔEGT_{gc}	MPL	RATE
33	31		3000	zero	1¼	-6	rich mixture		0.7	7.0	1¼	-4	rich mixture		2.3	23.0
39	38		2560	0.14	1¼	-	-	-	0.1	trace	1¼	-	-	-	1.9	10.8
40	34		2000	0.15	1	0	-	-	nil	zero	1	-2	-	-	0.9	1.8
42	29		5000	0.16	1-3/8	-2	+30	-75	nil	trace	1-3/8	-2	+45	+105	3.7	4.9
43	29		4600	0.12	1¼	0	-60	-60	nil	zero	1¼	0	-55	-55	3.2	4.3
45	30		2500	0.14	1¼	-	-	-	nil	zero	1¼	-	-	-	nil	zero
45	43	R	2900	0.15	1	+5	-25	+25	1.4	3.7	1	+5	+35	+25	5.6	14.6
46	42		2200	0.15	1	0	-	-	nil	zero	1	0	-	-	5.2	12.6
49	45		2900	0.15	1	+4	-	-	1.0	6.7	1	+4	-	-	5.7	38.0
50	42		4200	0.15	1¼	+4	lean mixture		0.3	2.6	1¼	+4	lean mixture		5.0	20.0
50	42		4200	0.15	1¼	+4	rich mixture		0.5	3.8	1¼	+4	rich mixture		4.2	31.5
50	42		4200	0.15	1½	+4	lean mixture		1.2	4.0	1¼	+4	lean mixture		3.7	11.1
52	15		3700	0.12	1¼	+2	+5	+20	nil	zero	1¼	-2	-30	-30	nil	zero
52	31		2900	0.15	1	+4	+25	+40	3.4	8.7	1	+4	-75	+90	0.4	1.7
54	54	R-	1000	0.16	1	+5	rich mixture		nil	zero	1	+2	rich mixture		1.8	21.6
57	52		3000	0.16	1¼	+4	0	-20	nil	zero	1¼	+5	-40	-40	3.0	7.2
57	52		3000	zero	1¼	+4	+10	+45	5.3	10.8	1¼	+5	-5	+80	1.2	3.0
59	59		4500	0.14	1¼	+6	-	-	1.0	4.3	1¼	+6	-	-	1.7	11.6
65	48		2800	0.13	1-1/8	+2	+5	+20	nil	zero	1-1/8	+2	-30	-30	nil	zero
69	62		3000	0.15	1¼	+8	-25	-35	nil	zero	1¼	+8	-25	-40	nil	zero

TABLE A-3

FLIGHT TEST DATA

LOW POWER

CONDITIONS				LEFT ENGINE							RIGHT ENGINE					
T	DP	WX	ALT	%EGHE	TP	CTT	ΔEGT_{pk}	ΔEGT_{gc}	MPL	RATE	TP	CTT	ΔEGT_{pk}	ΔEGT_{gc}	MPL	RATE
43	41	C	4000	zero	--	hot	---	---	---	----	idle	-4	---	---	2.4	0.8
			4000	zero	idle	-4	---	---	4.0	4.4	--	hot	---	---	---	---
54	54	R-	1000*	0.16	idle	+5	---	---	nil	zero	idle	+4	---	---	1.8	21.6
58	58	R	1300*	0.16	idle	--	---	---	0.6	0.8	idle	--	---	---	6.1	8.5
70	57		200*	0.15	idle	+8	---	---	nil	zero	idle	+8	---	---	0.5	0.4

* Ground run

TABLE A-4

FLIGHT TEST DATA

IDLE POWER

I. Steady-State Data

CONDITIONS				LEFT ENGINE			RIGHT ENGINE	
T	DP	WX	ELEV	%EGME	CTT	MPL	CTT	MPL
9	0		1050	0.15	--	nil	--	nil
19	19		840	0.15	--	nil	--	0.5
20	14		1050	0.14	--	0.8	--	nil
25	19		1050	0.16	--	nil	--	0.6
28	16		1210	0.16	--	nil	--	nil
39	16		1050	0.15	--	1.0	--	0.2
39	38		1050	0.14	--	0.4	--	0.4
40	30		1050	0.16	--	0.6	--	1.0
40	34		1050	0.15	--	0.4	--	0.7
41	39	R	1010	0.15	--	nil	--	quit
41	41	R-	980	0.15	--	nil	--	0.7
42	29		1050	0.16	--	nil	--	nil
42	42		1050	0.14	--	nil	--	(*)
43	18		200	0.15	--	nil	--	0.8
43	29		1050	0.12	--	0.8	--	0.6
43	36		1050	0.15	--	0.1	--	0.3
45	14		1050	0.14	--	nil	--	1.0
45	30		980	0.14	--	nil	--	nil
46	41	R-	490	0.15	--	nil	--	1.2
46	42		1050	0.15	--	0.1	--	0.2
49	45		1050	0.15	--	0.4	--	1.1
50	36		1050	0.16	--	0.2	--	0.8
51	25		1050	0.14	--	0.6	--	0.4
51	44		1050	0.15	(+18	0.2	+15	0.7
					(+18	0.5	+10	0.5
52	15		1050	0.12	--	0.8	--	0.2
52	33		1050	0.14	--	0.4	--	1.0
54	44		1050	0.15	--	0.2	--	0.7
55	54		1050	0.14	--	0.4	--	0.1
57	52		1050	0.15	--	nil	--	0.9
58	58		1050	0.16	--	0.2	--	0.8
59	59		1050	0.14	--	0.6	--	1.0
60	51		1050	0.16	--	0.9	--	0.6
62	45		1050	0.08	--	1.1	--	nil
63	59		1050	0.15	--	1.4	--	0.9
64	45		1050	0.15	--	nil	--	nil
64	52		1050	0.15	--	0.9	--	0.1
64	57		20	0.15	--	nil	--	nil
65	48		1050	0.14	--	nil	--	0.4
68	64	R+	150	0.14	--	0.2	--	nil
70	59		1050	0.15	--	0.7	--	0.5
70	65		20	zero	--	(*)	--	---
70	57		1050	0.16	--	nil	--	0.4
75	57		20	0.13	--	nil	--	nil
					(+8	0.3	+10	0.8
77	58		1050	0.15	(+10	0.5	+10	0.5
					(+10	1.1	+10	0.8
79	50		1050	0.15	--	0.2	--	0.9
80	58		1050	0.15	+10	0.5	+10	0.6
82	58		1050	0.15	+9	nil	+8	0.9
82	74		1050	0.15	--	nil	--	0.8

(*) Lost Power, carb heat added for safety

TABLE A-5

FLIGHT TEST DATA

IDLE POWER

II. Descent Data

Symbol	Units	Definition
T	deg F	Free Air Temperature
DP	deg F	Dew Point
WX		C = Clouds; R = Rain; R- = Light Rain; R+ = Heavy Rain
ALT	ft	Pressure altitude
%EGME	volume %	Volume percent of EGME in left engine's fuel
TP	arbitrary	Throttle position
CTT	deg C	Carburetor mixture temperature (Carburetor Throat Temperature)
ΔEGT	deg F	Difference in EGT values during carburetor ice tests. ΔEGT_{pk} is the change in the peak cylinder. ΔEGT_{oc} is the largest change in EGT of any of the cylinders.
MPL	in Hg	Manifold Pressure Lost during ice formation
RATE	in Hg/hr	Rate of manifold pressure drop
ELEV	ft	Airport Elevation

FLIGHT TEST DATA

Symbols and Definitions